THE MARINE ENVIRONMENT AND FISHERIES OF GEORGES BANK, NOVA SCOTIA: CONSIDERATION OF THE POTENTIAL INTERACTIONS ASSOCIATED WITH OFFSHORE PETROLEUM ACTIVITIES

Fisheries and Oceans Canada
Maritimes Region
Marine House
PO Box 1035
Dartmouth, Nova Scotia B2Y 4T3
Canada

2011

**Canadian Technical Report of
Fisheries and Aquatic Sciences 2945**

Fisheries and Oceans Canada
Canada
Pêches et Océans
Canada

Canada

Canadian Technical Report of Fisheries and Aquatic Sciences

Technical reports contain scientific and technical information that contributes to existing knowledge but which is not normally appropriate for primary literature. Technical reports are directed primarily toward a worldwide audience and have an international distribution. No restriction is placed on subject matter and the series reflects the broad interests and policies of Fisheries and Oceans Canada, namely, fisheries and aquatic sciences.

Technical reports may be cited as full publications. The correct citation appears above the abstract of each report. Each report is abstracted in the data base *Aquatic Sciences and Fisheries Abstracts.*

Technical reports are produced regionally but are numbered nationally. Requests for individual reports will be filled by the issuing establishment listed on the front cover and title page.

Numbers 1-456 in this series were issued as Technical Reports of the Fisheries Research Board of Canada. Numbers 457-714 were issued as Department of the Environment, Fisheries and Marine Service, Research and Development Directorate Technical Reports. Numbers 715-924 were issued as Department of Fisheries and Environment, Fisheries and Marine Service Technical Reports. The current series name was changed with report number 925.

Rapport technique canadien des sciences halieutiques et aquatiques

Les rapports techniques contiennent des renseignements scientifiques et techniques qui constituent une contribution aux connaissances actuelles, mais qui ne sont pas normalement appropriés pour la publication dans un journal scientifique. Les rapports techniques sont destinés essentiellement à un public international et ils sont distribués à cet échelon. Il n'y a aucune restriction quant au sujet; de fait, la série reflète la vaste gamme des intérêts et des politiques de Pêches et Océans Canada, c'est-à-dire les sciences halieutiques et aquatiques.

Les rapports techniques peuvent être cités comme des publications à part entière. Le titre exact figure au-dessus du résumé de chaque rapport. Les rapports techniques sont résumés dans la base de données *Résumés des sciences aquatiques et halieutiques.*

Les rapports techniques sont produits à l'échelon régional, mais numérotés à l'échelon national. Les demandes de rapports seront satisfaites par l'établissement auteur dont le nom figure sur la couverture et la page du titre.

Les numéros 1 à 456 de cette série ont été publiés à titre de Rapports techniques de l'Office des recherches sur les pêcheries du Canada. Les numéros 457 à 714 sont parus à titre de Rapports techniques de la Direction générale de la recherche et du développement, Service des pêches et de la mer, ministère de l'Environnement. Les numéros 715 à 924 ont été publiés à titre de Rapports techniques du Service des pêches et de la mer, ministère des Pêches et de l'Environnement. Le nom actuel de la série a été établi lors de la parution du numéro 925.

Canadian Technical Report of
Fisheries and Aquatic Sciences 2945

2011

THE MARINE ENVIRONMENT AND FISHERIES OF GEORGES BANK, NOVA SCOTIA: CONSIDERATION OF THE POTENTIAL INTERACTIONS ASSOCIATED WITH OFFSHORE PETROLEUM ACTIVITIES

by

Fisheries and Oceans Canada
Maritimes Region
Marine House
P.O. Box 1035
Dartmouth, Nova Scotia, Canada
B2Y 4T3

Canadian Technical Report of Fisheries and Aquatic Sciences

Technical reports contain scientific and technical information that contributes to existing knowledge but which is not normally appropriate for primary literature. Technical reports are directed primarily toward a worldwide audience and have an international distribution. No restriction is placed on subject matter and the series reflects the broad interests and policies of Fisheries and Oceans Canada, namely, fisheries and aquatic sciences.

Technical reports may be cited as full publications. The correct citation appears above the abstract of each report. Each report is abstracted in the data base *Aquatic Sciences and Fisheries Abstracts*.

Technical reports are produced regionally but are numbered nationally. Requests for individual reports will be filled by the issuing establishment listed on the front cover and title page.

Numbers 1-456 in this series were issued as Technical Reports of the Fisheries Research Board of Canada. Numbers 457-714 were issued as Department of the Environment, Fisheries and Marine Service, Research and Development Directorate Technical Reports. Numbers 715-924 were issued as Department of Fisheries and Environment, Fisheries and Marine Service Technical Reports. The current series name was changed with report number 925.

Rapport technique canadien des sciences halieutiques et aquatiques

Les rapports techniques contiennent des renseignements scientifiques et techniques qui constituent une contribution aux connaissances actuelles, mais qui ne sont pas normalement appropriés pour la publication dans un journal scientifique. Les rapports techniques sont destinés essentiellement à un public international et ils sont distribués à cet échelon. Il n'y a aucune restriction quant au sujet; de fait, la série reflète la vaste gamme des intérêts et des politiques de Pêches et Océans Canada, c'est-à-dire les sciences halieutiques et aquatiques.

Les rapports techniques peuvent être cités comme des publications à part entière. Le titre exact figure au-dessus du résumé de chaque rapport. Les rapports techniques sont résumés dans la base de données *Résumés des sciences aquatiques et halieutiques*.

Les rapports techniques sont produits à l'échelon régional, mais numérotés à l'échelon national. Les demandes de rapports seront satisfaites par l'établissement auteur dont le nom figure sur la couverture et la page du titre.

Les numéros 1 à 456 de cette série ont été publiés à titre de Rapports techniques de l'Office des recherches sur les pêcheries du Canada. Les numéros 457 à 714 sont parus à titre de Rapports techniques de la Direction générale de la recherche et du développement, Service des pêches et de la mer, ministère de l'Environnement. Les numéros 715 à 924 ont été publiés à titre de Rapports techniques du Service des pêches et de la mer, ministère des Pêches et de l'Environnement. Le nom actuel de la série a été établi lors de la parution du numéro 925.

Canadian Technical Report of
Fisheries and Aquatic Sciences 2945

2011

THE MARINE ENVIRONMENT AND FISHERIES OF GEORGES BANK, NOVA SCOTIA: CONSIDERATION OF THE POTENTIAL INTERACTIONS ASSOCIATED WITH OFFSHORE PETROLEUM ACTIVITIES

by

Fisheries and Oceans Canada
Maritimes Region
Marine House
P.O. Box 1035
Dartmouth, Nova Scotia, Canada
B2Y 4T3

© Her Majesty the Queen in Right of Canada, 2011.
Cat. No. FS 97-6/2945E ISSN 0706-6457

Correct citation for this publication:

Fisheries and Oceans Canada. 2011. The Marine Environment and Fisheries of Georges Bank, Nova Scotia: Consideration of the Potential Interactions Associated with Offshore Petroleum Activities. Can. Tech. Rep. Fish. Aquat. Sci. 2945: xxxv + 492pp.

PREFACE AND ACKNOWLEDGEMENT

This technical report was prepared by Fisheries and Oceans Canada (DFO), Maritimes Region, to provide a 'state-of-knowledge' of the Georges Bank marine ecosystem (e.g. oceanography, marine habitat, marine species, and aquatic species at risk), fisheries (including Aboriginal fisheries) and other ocean users of the area, socio-economic profile of the fisheries, and an overview of DFO programs that support oceans management – the report places emphasis on Canada's portion of Georges Bank. The report also outlines the potential interactions associated with typical offshore petroleum activities that may arise in context of marine ecosystems and fisheries, based on observations from other offshore petroleum development regions. The major conclusions of the report are presented in the Executive Summary and at the end of each chapter – a concluding chapter is not provided in the report. In some sections, the report may refer to legislation, regulations, and policies that are under the authority of other federal agencies. The reader is encouraged to contact the applicable federal authority directly for further information.

This report is an update to previous reviews of the potential environmental interactions of offshore petroleum exploratory drilling on Georges Bank undertaken by Gordon (1988) and Boudreau et al. (1999). As activities associated with offshore petroleum development extend far beyond the exploration phase (i.e. more than 25 years rather than months), the scope of the technical report has been expanded to include the potential interactions associated with offshore petroleum development. Interactions associated with development were not considered in the earlier reviews. This report was prepared under the auspices of the DFO Georges Bank Moratorium Review Committee. The science-based chapters of this report (i.e. Chapters 2.0 and 3.0) were subject to two peer-review meetings of the Canadian Secretariat for Science Advice (CSAS) Regional Advisory Process (RAP) at Dartmouth, Nova Scotia, and were subsequently published as CSAS Research Documents. Participants of the CSAS meetings provided comments, suggestions, and revisions to the information contained in the science-based chapters. They also had opportunity to comment on the report in its entirety. More details regarding these publications can be found on the CSAS website: www.dfo-mpo.gc.ca/csas.

Sincere appreciation is given to the reviewers, whose input has contributed to a strengthened report. Special thanks is also is given to the Canada-Nova Scotia Offshore Petroleum Board, Environment Canada, National Defence Canada, and Natural Resources Canada for providing content that has advanced the state-of-knowledge presented herein. Last, thank you to Francis Kelly for providing support with graphic design.

LIST OF CONTRIBUTORS

Editors

Editors:	Kristian Curran, Kenneth Lee, Eddy Kennedy, Tana Worcester, Lottie Bennett

Chapter 1.0: Introduction

Lead Author:	Kristian Curran

Chapter 2.0: Marine Ecosystem

Lead Author:	Eddy Kennedy
Contributors:	
Circulation and Hydrographic Structure	Peter Smith, Charles Hannah
Geology	John Wade (Emeritus Scientist, Geological Survey of Canada (Atlantic)
Sedimentology	Brent Law; Tim Milligan
Plankton	Catherine Johnson, William K.W. Li, W. Glen Harrison
Benthic Invertebrates	Ellen Kenchington (corals), Jessica Sameoto and Ian Jonsen (scallop), John Tremblay (lobster)
Finfish	Gary Melvin (herring), Francois Gregoire (mackerel), Yanjun Wang, Lou VanEeckhaute, Heath Stone, Kirsten Clark, Peter Comeau, Mark Fowler, and Jim Simon (ground fish)
Sharks	Steve Campana
Large Pelagics	Stacy Paul
Marine Mammals	Lei Harris, Kent Smedbol, Don Bowen
Species at Risk/Species of Concern	Lei Harris
Marine Birds	Carina Gjerdrum (Environment Canada)

Chapter 3.0: Potential Interactions Associated with Offshore Petroleum Activities

Lead Author:	Kenneth Lee
Contributors:	
Seismic Noise	Norm Cochrane, Tana Worcester

Drill Muds	Peter Cranford, Zhengkai Li, Shelley Armsworthy, Haibo Niu, Adam Drozdowski
Spills, Blowouts, and Malfunctions	Monica Romero
Produced Water	Jerry Neff, Haibo Niu, Brian Robinson, and Susan Cobanli

Chapter 4.0: Fisheries and Other Ocean Users

Lead Authors:	Kristian Curran, Andrew Newbould
Contributors:	
Aboriginal Fisheries	Gary Weber
Scallop Fishery	Greg Stevens
Lobster and Crab Fisheries	Mike Eagles
Groundfish Fisheries	Jon Hansen
Large Pelagics Fisheries	Laura Hussey
Herring Fisheries	Christa Waters
Other Ocean Users	Glen Herbert, Anna Serdynska
Interactions with Fisheries	Glen Herbert

Chapter 5.0: Socio-economics of the Commercial Fisheries

Lead Author:	Marielle Wilson
Contributors:	
Socio-economic Analysis	Doreen Liew, Cory Large

Chapter 6.0: Oceans, Fisheries, Species at Risk, and Emergency Preparedness Management

Lead Author:	Kristian Curran
Contributors:	
Oceans Programs	Glen Herbert
Aboriginal Fisheries Programs	Gary Weber
Fisheries Licencing	Andrew Newbould
Sustainable Fisheries Framework	Chris Annand
Marine Stewardship Council	Stefan Leslie
Species at Risk	Joe Crocker
Marine Emergency Preparedness	Joe Leclair

Appendix

Lead Author:	Daphne Themalis

ACRONYMS AND ABBREVIATIONS

AAROM	Aboriginal Aquatic Resources and Oceans Management
AICFI	Aboriginal Integrated Commercial Fisheries Initiative
AFSAR	Aboriginal Funds for Species at Risk
AFS	Aboriginal Fisheries Strategy
AP	Alkylphenol
APE	Alkylphenol Ethoxylate
AUV	Autonomous Underwater Vehicle
BAT	Best Available Technology
BBLT	Bottom Boundary Layer Transport Model
BECPELAG	Biological Effects of Contaminants in Pelagic Ecosystems
BOP	Blowout Prevention System
BTEX	Benzene, Toluene, Ethylbenzene, and Xylenes
CANUSLANT	JCP Atlantic Geographic Annex
CCG	Canadian Coast Guard
CETAP	Cetacean and Turtle Assessment Program (CETAP)
CHP	Conservation Harvesting Plan
CITES	Convention on International Trade in Endangered Species
CNLOPB	Canada-Newfoundland and Labrador Offshore Petroleum Board
CNSOPB	Canada-Nova Scotia Offshore Petroleum Board
COOGER	Centre for Offshore Oil, Gas and Energy Research
COSEWIC	Committee on the Status of Endangered Wildlife in Canada
CPUE	Catch per Unit Effort
CSAS	Canadian Science Advisory Secretariat
CV	Coefficient of Variance
CW	Carapace Width
DDT	Dichlorodiphenyltrichloroethane
DFO	Fisheries and Oceans Canada
DGGE	Denaturing Gradient Gel Electrophoresis
DMC	Dockside Monitoring Company
DND	National Defence Canada
DREAM	Dose-related Risk and Effect Assessment Model
E&P	Exploration and Production
EAM	Ecosystem Approach to Management
EBM	Ecosystem Based Management
ECSAS	Eastern Canada Seabird at Sea
EEM	Environmental Effects Monitoring
EIA	Environmental Impact Assessment
EIF	Environmental Impact Factor
EOR	Enhanced oil recovery
EROD	Ethoxyresorufin-*o*-deethylase
ESRF	Environmental Studies Research Fund
ESSIM	Eastern Scotian Shelf Integrated Management
FAO	Food and Agriculture Organization (United Nations)
FPSO	Floating, Production, Storage, and Offloading

FSU	Former Soviet Union
GBS	Gravity Base Structure
GLOBEC	Global Ocean Ecosystem Dynamics
GOMOOS	Gulf of Maine Ocean Observing System
GOOMEX	Gulf of Mexico Offshore Operations Monitoring Experiment
GSC	Geological Survey of Canada
ICCAT	International Commission for the Conservation of Atlantic Tuna
IFMP	Integrated Fisheries Management Plan
IUCN	International Union for Conservation of Nature
JCP	Marine Pollution Contingency Plan
K_{ow}	Octanol/Water Partition Coefficient
LFA	Lobster Fishing Area
LSW	Labrador Slope Water
LTMO	Low Toxicity Mineral Oil
LPS	Lipopolysaccharides
MARFIS	Marine Fishery Information System
MARLANT	Maritime Forces Atlantic
MARMAP	Marine Resources Monitoring, Assessment, and Prediction Program
MARPOL	International Convention for the Prevention of Pollution from Ships
MEG	Monoethylene glycol
MFO	Mixed-function Oxidase
MPA	Marine Protected Area
MRI	*Marshall* Response Initiative
MSC	Marine Stewardship Council
MSY	Maximum Sustainable Yield
NAFO	Northwest Atlantic Fisheries Organization
NAO	North Atlantic Oscillation
NEB	National Energy Board
NEC CCA	Northeast Channel Coral Conservation Area
NEFSC	Northeast Fisheries Science Center
NEP	Northeast Peak (of Georges Bank)
NMFS	National Marine Fisheries Service
NOAA	National Oceanic and Atmospheric Administration
NORM	Naturally Occurring Radioactive Material
OBM	Oil Based Mud
OCSG	Offshore Chemical Selection Guidelines
OGP	International Association of Oil and Gas Producers
OMA	Oil-mineral Aggregate
OOC	Offshore Operators Committee
PAH	Polycyclic Aromatic Hydrocarbon
PAM	Passive Acoustic Monitoring
PCB	Polychlorinated Biphenyls
PEC	Predicted Environmental Concentration
PIROP	Programme Integré de Recherche sur les Oiseaux Pélagiques
PNEC	Predicted No-Effect Concentration

POM	Princeton Ocean Model
RAP	Regional Advisory Process
RB	Respiratory Burst
RCR	Risk Characterization Ratios
REET	Regional Environmental Emergency Team
RMS	Root Mean Square
SARA	Species at Risk Act
SBM	Synthetic Based Mud
SEL	Sound Exposure Level
SFA	Scallop Fishing Area
SIMAP	Spill Impact Model Application Package
SOEP	Sable Offshore Energy Project
SSB	Spawning Stock Biomass
TAC	Total Allowable Catch
TMGC	Transboundary Management Guidance Committee
TOC	Total Organic Carbon
TPH	Total Petroleum Hydrocarbons
TRAC	Transboundary Resource Assessment Committee
TTS	Temporary Threshold Shift
UM3	Three-dimensional Updated Merge
U.S.	United States of America
U.S. EPA	United States Environmental Protection Agency
UXO	Unexploded Explosive Ordnance
VEC	Valued Ecosystem Component
VPA	Virtual Population Analysis
WCR	Warm Core Ring
WBM	Water Based Mud
WHMIS	Workplace Hazardous Material Information System
WOR	Produced Water to Oil Ratio
WSW	Warm Slope Water

TABLE OF CONTENTS

LIST OF TABLES xv

LIST OF FIGURES xvii

ABSTRACT xxiv

RÉSUMÉ xxv

EXECUTIVE SUMMARY xxvi

1.0 INTRODUCTION 1
  1.1 INTRODUCTION 1

2.0 MARINE ECOSYSTEM 5
  2.1 GENERAL TOPOGRAPHY 5
  2.2 CIRCULATION, HYDROGRAPHIC STRUCTURE, AND MIXING 6
  2.3 GEOLOGY 21
  2.4 SEDIMENTOLOGY 23
  2.5 TROPHIC INTERACTIONS 28
  2.6 PLANKTON 31
    2.6.1 Bacterioplankton 31
    2.6.2 Phytoplankton 33
    2.6.3 Zooplankton 36
  2.7 BENTHIC INVERTEBRATES 40
    2.7.1 Ahermatypic Corals 42
    2.7.2 Sea Scallop 46
    2.7.3 Lobster 49
    2.7.4 Crab 55
      2.7.4.1 Deep-sea Red Crab 55
      2.7.4.2 Jonah Crab 57
    2.7.5 Squid 59
      2.7.5.1 Northern Shortfin Squid 59
      2.7.5.2 Longfin Inshore Squid 61
  2.8 FINFISH 63
    2.8.1 Herring 63
    2.8.2 Mackerel 69
    2.8.3 Sand Lance 71
    2.8.4 Atlantic Cod 74

2.8.5 Haddock....................79
2.8.6 Pollock....................86
2.8.7 Monkfish....................89
2.8.8 Cusk....................92
2.8.9 Redfish....................95
2.8.10 Wolfish....................98
  2.8.10.1 Atlantic Wolffish....................102
2.8.11 Atlantic Halibut....................104
2.8.12 Yellowtail Flounder....................107
2.8.13 Witch Flounder....................111
2.8.14 Skates....................114
  2.8.14.1 Winter Skate....................114
  2.8.14.2 Little Skate....................117
  2.8.14.3 Thorny Skate....................120
  2.8.14.4 Smooth Skate....................123
  2.8.14.5 Barndoor Skate....................125
2.8.15 Spiny Dogfish....................127
2.8.16 Black Dogfish....................130
2.8.17 Large Pelagics....................132
  2.8.17.1 Swordfish....................132
  2.8.17.2 Bluefin Tuna....................135
  2.8.17.3 Yellowfin Tuna....................138
  2.8.17.4 Bigeye Tuna....................141
  2.8.17.5 Albacore Tuna....................143
  2.8.17.6 Porbeagle Shark....................145
  2.8.17.7 Thresher Shark....................147
  2.8.17.8 Basking Shark....................148
  2.8.17.9 Shortfin Mako Shark....................150
  2.8.17.10 Blue Shark....................151
  2.8.17.11 Smooth Hammerhead Shark....................153
  2.8.17.12 White Shark....................154
2.9 MARINE MAMMALS....................156
2.9.1 Cetaceans....................156
  2.9.1.1 North Atlantic Right Whale....................157
  2.9.1.2 Fin Whale....................160
  2.9.1.3 Sei Whale....................161
  2.9.1.4 Minke Whale....................163
  2.9.1.5 Humpback Whale....................164
  2.9.1.6 Sperm Whale....................165
  2.9.1.7 Pilot Whale....................167
  2.9.1.8 Bottlenose Dolphin....................167
  2.9.1.9 Atlantic White-sided Dolphin....................169
  2.9.1.10 Common Dolphin....................170
  2.9.1.11 Striped Dolphin....................171
  2.9.1.12 Harbour Porpoise....................172
  2.9.1.13 Blue Whale....................173

2.9.1.14 Sowerby's Beaked Whale 175
2.9.2 Seals 176
2.9.2.1 Grey Seals 176
2.9.2.2 Harbour Seals 179
2.10 SEA TURTLES 180
2.10.1 Leatherback Turtle 181
2.10.2 Loggerhead Turtle 184
2.11 MARINE BIRDS 186
2.11.1 Greater Shearwater 188
2.11.2 Other Shearwaters 189
2.11.3 Red Phalarope 190
2.11.4 Other Phalaropes 191
2.11.5 Wilson's Storm-Petrels 192
2.11.6 Other Storm-Petrels 193
2.11.7 Thick-Billed Murre 193
2.11.8 Other Alcids 194
2.11.9 Northern Fulmar 195
2.11.10 Herring Gull 196
2.11.11 Great Black-backed Gull 198
2.11.12 Black-legged Kittiwake 199
2.11.13 Northern Gannet 200
2.11.14 Other Laridae 202
2.11.15 Other Birds 202
2.12 STATE OF KNOWLEDGE 203
2.13 CONCLUSION 204

3.0 POTENTIAL INTERACTIONS ASSOCIATED WITH OFFSHORE PETROLEUM ACTIVITIES 206

3.1 PETROLEUM POTENTIAL OF GEORGES BANK 206
3.2 SEISMIC NOISE 207
3.2.1 Impacts of Marine Environment 211
3.2.1.1 Impacts on Fish and Invertebrates 211
3.2.1.2 Impacts on Marine Mammals 218
3.2.1.3 Impacts on Sea Turtles 222
3.2.2 Mitigation Measures 224
3.2.3 Analysis of Risk, Knowledge Gaps, and Reseearch Needs 226
3.3 DRILL MUDS 229
3.3.1 Impacts on Marine Environment 235
3.3.1.1 Acute Impacts 235
3.3.1.2 Sublethal Impacts 236
3.3.1.3 Tainting Impacts 241
3.3.2 Dispersion and Transport 241
3.3.2.1 Physical Transport Models 242
3.3.2.2 Physico-chemical Models 244
3.3.2.3 Risk Assessment Models 245

3.3.3 Environmental Effects Monitoring 247
3.3.3.1 Detection Zones 247
3.3.3.2 Biodiversity and Abundance 249
3.3.3.3 Toxicity and Biological Effects 250
3.3.3.4 Bioaccumulation and Taint 251
3.4 PRODUCED WATER 252
3.4.1 Chemical Composition 253
3.4.1.1 Total Organic Carbon 254
3.4.1.2 Organic Acids 255
3.4.1.3 Petroleum Hydrocarbons...255
3.4.1.4 Phenols 256
3.4.1.5 Salinity and Inorganic Ions 258
3.4.1.6 Metals..258
3.4.1.7 Radioisotopes 260
3.4.1.8 Production Chemicals 261
3.4.2 Treatment 262
3.4.3 Fate of Discharge in the Ocean 264
3.4.3.1 Plume Dispersion Models..265
3.4.3.2 Chemical Fate and Transport Models 267
3.4.3.3 Field Measurements of Produced Water Dilutions 269
3.4.4 Impacts on Marine Environment 271
3.4.4.1 Impacts on Pelagic Organisms..272
3.4.4.2 Accumulation and Impacts in Sediments.................................272
3.4.4.3 Toxicity 273
3.4.4.4 Bioaccumulation, Biomarkers, and Exposure 274
3.4.5 Ecological Risk of Produced Water Discharges...............................281
3.4.6. Further Research Needs...286
3.5 NATURAL SEEPAGE, SPILLS, BLOWOUTS, AND MALFUNCTIONS....288
3.5.1 Natural Seepage...288
3.5.2 Spills and Blowouts...288
3.5.3 Oil Spill Modeling 293
3.5.3.1 Fate and Transport Models 294
3.5.3.2 Biological Effect and Risk Assessment Models 295
3.5.4 Impacts on Marine Environment 296
3.5.5 Oil Spill Countermeasures 299
3.6 INFRASTRUCTURE, OPERATIONS, AND DECOMISSIONING.............302
3.6.1 Marine Noise...302
3.6.2 Influence of Light 303
3.6.3 Disposal of Wastes 303
3.6.4 Atmospheric Emissions...304
3.6.5 Decomissioning 305
3.7 OTHER OFFSHORE PETROLEUM REGIONS 305
3.7.1 Scotian Shelf and Grand Banks...305
3.7.2 North Sea..307
3.7.3 Gulf of Mexico...307
3.8 CONCLUSION...308

4.0 FISHERIES AND OTHER OCEAN USERS...314

4.1 ABORIGINAL FISHERIES...314
4.2 COMMERCIAL FISHERIES..314
4.2.1 Shellfish Fisheries...316
4.2.1.1 Scallop Fishery...316
4.2.1.2 Lobster and Crab Fisheries..319
4.2.2 Groundfish Fisheries..322
4.2.3 Pelagic Fisheries...325
4.2.3.1 Swordfish and Tuna (Yellowfin, Bigeye, Albacore) Fisheries.....325
4.2.3.2 Blue Fin Tuna Fishery...330
4.2.3.3 Herring Fishery...332
4.3 OTHER OCEAN USERS..333
4.3.1 Offshore Petroleum..333
4.3.2 Maritime Transportation...336
4.3.3 Scientific Research...337
4.3.4 Military..339
4.3.5 Submarine Telecommunications..341
4.4 POTENTIAL INTERACTION OF PETROLEUM ACTIVITY WITH FISHING..342
4.4.1 Access..343
4.4.2 Vessel and Gear Interactions..344
4.4.3 Accidental Spills...345
4.4.4 Mitigation Measures...345
4.5 CONCLUSION..346

5.0 FISHERIES SOCIO-ECONOMIC PROFILE...349

5.1 ANNUAL TOTAL LANDED VALUE (1998–2008)..349
5.2 ABORIGINAL FISHERIES...351
5.3 ANNUAL LANDINGS & LANDED VALUES BY FISHERY (1998–2008)...351
5.3.1 Shellfish Fisheries...351
5.3.1.1 Scallop Fishery...351
5.3.1.2 Lobster Fishery...353
5.3.1.3 Crab Fishery..355
5.3.2 Groundfish Fisheries..356
5.3.3 Pelagics Fisheries..358
5.3.3.1 Swordfish Fishery...358
5.3.3.2 Tuna Fishery..360
5.3.3.3 Herring and Other Pelagics Fisheries....................................362
5.4 MONTHLY LANDED VALUES BY FISHERY (2008)....................................364
5.5 LANDED VALUES PER NOVA SOCTIA COUNTY (2007)................................365
5.6 FINAL PRODUCT VALUES (1998–2008)..367
5.7 EMPLOYMENT ASSOCIATED WITH FISHERIES...369
5.7.1 Employment from Fishing (2008)..369
5.7.2 Employment from Seafood Processing (2008)..................................370
5.7.3 Employment per Nova Scotia County...372
5.8 CONCLUSION..374

6.0 OCEANS, FISHERIES, SPECIES AT RISK, AND EMERGENCY PREPAREDNESS MANAGEMENT......376
- 6.1 OCEANS MANAGEMENT......376
  - 6.1.1 Integrated Management......376
  - 6.1.2 Ecosystem Approach to Management......377
  - 6.1.3 Marine Protected Areas......378
  - 6.1.4 Environmental Assessment......379
  - 6.1.5 Monitoring......380
- 6.2 FISHERIES MANAGEMENT......381
  - 6.2.1 Fish Licenses......381
  - 6.2.2 Aboriginal Fisheries Programs......382
  - 6.2.3 Sustainable Fisheries Framework......384
  - 6.2.4 Marine Stewardship Council Certification......385
- 6.3 SPECIES AT RISK MANAGEMENT......386
- 6.4 MARINE PREPAREDNESS AND RESPONSE MANAGEMENT......388
- 6.5 CONCLUSION......391

REFERENCES......393

APPENDIX: MARINE SPECIES OF GEORGES BANK......479

LIST OF TABLES

Table 2-1. Timing of life stages for select invertebrates and fish species. 29

Table 2-2. Coral taxa known to reside in the Georges Bank moratorium area. ..44

Table 2-3. Seasonal abundance of cetaceans found on Georges Bank. 156

Table 2-4. Seasonal occurrence of seabirds found on Georges Bank. 188

Table 3-1. Estimates of days of lost growth of scallops. 238

Table 3-2. Concentrations of natural chemicals in produced water. 254

Table 3-3. Concentrations of PAHs in produced water. 257

Table 3-4. Concentrations of metals in produced water. 259

Table 3-5. Activities of ^{226}Ra and ^{228}Ra in produced water. 261

Table 3-6. Production chemicals used on North Sea oil and gas platforms......262

Table 3-7. Concentrations of oil and grease in produced water disposal. 262

Table 3-8. Concentrations and dilutions of PAHs produced water, Australia ...270

Table 3-9. Toxicity of more than 400 produced water samples. 273

Table 3-10. Historical large oil spills from offshore well blowouts. 290

Table 3-11. Number of wells in the Gulf of Mexico by water depth..................307

Table 4-1. Scallop total allowable catch in moratorium area 319

Table 4-2. Groundfish total allowable catch in moratorium area 325

Table 5-1. Landed value by NAFO 5ZE fishery, 1998-2008p 350

Table 5-2. Scallop landings and landed values NAFO 5ZE, 1998-2008p 353

Table 5-3. Lobster landings and landed values NAFO 5ZE, 1998-2008p.........354

Table 5-4. Crab landings and landed values NAFO 5ZE, 1998-2008p 356

Table 5-5. Groundfish landings and landed values NAFO 5ZE, 1998-2008p...357

Table 5-6. Swordfish landings and landed values NAFO 5ZE, 1998-2008p 359

Table 5-7. Tuna landings and landed values NAFO 5ZE, 1998-2008p 361

Table 5-8. Pelagics landings and landed values NAFO 5ZE, 1998-2008p 363

Table 5-9. Landed value NAFO 5ZE fisheries by County, 2008 365

Table 5-10. Vessel landed value NAFO 5ZE fishery by County, 2008 366

Table 5-11. Final product value by NAFO 5ZE fishery, 1998-2008p 368

Table 5-12. Estimated employment from NAFO 5ZE fisheries, 2008 369

Table 5-13. Estimated vessel income from NAFO 5ZE fisheries, 2008............370

Table 5-14. Estimated peak month employment NAFO 5ZE fisheries, 2008....371

Table 5-15. Estimated full year employment NAFO 5ZE fisheries, 2008..........372

Table 5-16. Estimated income from processing NAFO 5ZE fisheries, 2008 372

Table 5-17. Estimated employment of fish harvesting and processing, 2005 ..373

LIST OF FIGURES

Figure 1-1. Location of Georges Bank and the moratorium area 1

Figure 1-2. Submarine features of Georges Bank and surrounding area 2

Figure 2-1. Bathymetry of the Northeast Peak of Georges Bank. 5

Figure 2-2. M2 tidal excursions of Northeast Peak of Georges Bank. 7

Figure 2-3. Hydrographic structure and seasonal mean circulation pattern 8

Figure 2-4. Modeled mean water velocities for winter and summer seasons. 9

Figure 2-5. Density differences of surface waters and waters at 50 m depth..... 11

Figure 2-6. Vertical structure associated with the seasonal frontal system 12

Figure 2-7. Trajectories of three drifters deployed on Georges Bank. 13

Figure 2-8. Georges Bank and Gulf of Maine currents for stratified season....... 16

Figure 2-9. Near-surface drifter tracks of Georges Bank.................................. 17

Figure 2-10. Labrador Slope Water intrusion of shelf break and deep basins.... 20

Figure 2-11. Penetration of Labrador Slope Water into the Gulf of Maine.......... 20

Figure 2-12. Depth to the breakup unconformity and major tectonic elements. . 21

Figure 2-13. Geology cross-section of Georges Bank Basin to Scotian Basin... 22

Figure 2-14. Contours on the top of the Jurassic. 23

Figure 2-15. Bottom sediment grain-size on Canada's Georges Bank............... 24

Figure 2-16. Frictional velocities of Scotian Shelf produced from tidal currents. 25

Figure 2-17. Marine species that prefer fine-grained sediments as a substrate. 27

Figure 2-18. Marine species that prefer coarse-grained sediment substrate. 28

Figure 2-19. Depth-related covariation of bacterioplankton and chlorophyll....... 32

Figure 2-20. Georges Bank phytoplankton.. 34

Figure 2-21. Gulf of Maine Area phytoplankton physiographic regions. 35

Figure 2-22. Mean annual abundance of Calanus finmarchicus. 38

Figure 2-23. Mean annual abundance of various zooplankton species............. 39

Figure 2-24. Benthic locations sampled from 1994-2000. 42

Figure 2-25. Major coral groups of the Georges Bank moratorium area.. 43

Figure 2-26. Major coral groups of moratorium area and surrounding regions. . 45

Figure 2-27. Distribution of sea scallop catches of Georges Bank, 2008. 47

Figure 2-28. Sea scallop survey biomass indices for Georges Bank Zone ‘a’.... 48

Figure 2-29. Distribution of American lobster in the Northwest Atlantic............. 50

Figure 2-30. Distribution of American lobster landings from LFA 41. 50

Figure 2-31. Lobster landings from LFA 41. 51

Figure 2-32. Estimates of lobster spawning stock biomass............................... 52

Figure 2-33. Reference abundance for Georges Bank lobster. 52

Figure 2-34. Annual effective exploitation rate for Georges Bank lobster. 53

Figure 2-35. Distribution of deep-sea red crab and Jonah crab.. 56

Figure 2-36. Jonah Crab landings. 58

Figure 2-37. Distribution and spawning strategy of Atlantic herring stocks. 64

Figure 2-38. Trends in herring stock complex biomass and recruitment.. 65

Figure 2-39. Distribution and abundance of Atlantic herring of Georges Bank. 66

Figure 2-40. Potential Atlantic herring spawning areas on Georges Bank. 67

Figure 2-41. Distribution of hatched Atlantic herring larvae on Georges Bank... 68

Figure 2-42. Distribution of Atlantic mackerel in the Northwest Atlantic.. 69

Figure 2-43. Map of mackerel bottom trawl catches on Georges Bank............. 70

Figure 2-44. Distribution of sand lance on Georges Bank. 72

Figure 2-45. Biomass estimate northern sand lance from summer RV survey. .73

Figure 2-46. Distribution of Atlantic cod in the northwest Atlantic Ocean. 75

Figure 2-47. Biomass and recruitment of eastern Georges Bank cod. 76

Figure 2-48. Movement corridors on Georges Bank for Atlantic cod. 77

Figure 2-49. Distribution of Atlantic cod on eastern Georges Bank. 77

Figure 2-50. Distribution and abundance Atlantic cod eggs on Georges Bank. .78

Figure 2-51. Fishing distribution of Atlantic cod on eastern Georges Bank. 79

Figure 2-52. Distribution of haddock in the northwest Atlantic Ocean.. 80

Figure 2-53. Biomass and recruitment of eastern Georges Bank haddock. 81

Figure 2-54. Average distribution of haddock of Georges Bank by age group ...82

Figure 2-55. Distribution and abundance of haddock eggs from MARMAP. 84

Figure 2-56. Distribution and abundance of haddock eggs from GLOBEC. 85

Figure 2-57. Distribution of pollock in the northwest Atlantic Ocean. 87

Figure 2-58. Trends in Age 4+ biomass and Age 2 recruitment of pollock.. 88

Figure 2-59. Distribution of monkfish in the northwest Atlantic Ocean. 90

Figure 2-60. Distribution and abundance of cusk in northwest Atlantic Ocean. .93

Figure 2-61. Catch per unit effort of cusk by quota year. 94

Figure 2-62. Distribution of redfish in the northwest Atlantic Ocean. 96

Figure 2-63. Distribution of northern wolfish in the offshore of Nova Scotia. 99

Figure 2-64. Distribution of spotted wolfish in the offshore of Nova Scotia 100

Figure 2-65. Distribution of Atlantic wolfish in the offshore of Nova Scotia. 101

Figure 2-66. Distribution of Atlantic wolfish on Georges Bank. 101

Figure 2-67. Biomass of Scotian Shelf Atlantic wolffish. 103

Figure 2-68. Biomass of Georges Bank Atlantic wolffish.................................... 103

Figure 2-69. Distribution of Atlantic halibut in the northwest Atlantic Ocean. ... 105

Figure 2-70. Distribution of yellowtail flounder in northwest Atlantic Ocean. 108

Figure 2-71. Spawning Biomass and Age 1 recruitment Yellowtail Flounder. .. 109

Figure 2-72. Distribution of witch flounder in the northwest Atlantic Ocean.. ... 112

Figure 2-73. Distribution of winter skate on Georges Bank. 115

Figure 2-74. Biomass and abundance of winter skate 116

Figure 2-75. Distribution of little skate on Georges Bank. 118

Figure 2-76. Biomass and abundance of little skate.. 119

Figure 2-77. Distribution of thorny skate on Georges Bank................................ 121

Figure 2-78. Biomass and abundance of thorny skate 122

Figure 2-79. Distribution of smooth skate on Georges Bank............................. 123

Figure 2-80. Biomass and abundance of smooth skate 124

Figure 2-81. Distribution of barndoor skate on Georges Bank. 125

Figure 2-82. Biomass and abundance of barndoor skate.................................. 126

Figure 2-83. Distribution of spiny dogfish in the northwest Atlantic Ocean....... 128

Figure 2-84. Distribution of black dogfish in the northwest Atlantic Ocean....... 131

Figure 2-85. Distribution of Canadian longline catches of swordfish.. 133

Figure 2-86. Relative biomass and fishing mortality North Atlantic swordfish... 134

Figure 2-87. Distribution of bluefin tuna caught in the Georges Bank area.. 136

Figure 2-88. Spawning biomass and recruitment west Atlantic bluefin tuna 137

Figure 2-89. Distribution of yellowfin tuna caught by Canadian longline.. 139

Figure 2-90. Yellowfin tuna relative biomass and relative fishing mortality 140

Figure 2-91. Distribution of bigeye tuna caught by Canadian longline.. 141

Figure 2-92. Bigeye tuna relative biomass and relative fishing mortality..........142

Figure 2-93. Distribution of albacore tuna caught by Canadian longline.. 143

Figure 2-94. Albacore tuna relative biomass and relative fishing mortality.......144

Figure 2-95. Porbeagle shark distribution by bottom trawl on Georges Bank.. 145

Figure 2-96. North Atlantic right whale distribution in the western Atlantic.......158

Figure 2-97. Adult grey seal distribution in Georges Bank area.. 177

Figure 2-98. Number of grey seal pups born at Sable Island, 1962-2007 178

Figure 2-99. Distribution of leatherback turtles in eastern Canada...................182

Figure 2-100. Year-round distribution of seabirds in eastern Canada 187

Figure 3-1. Schematic of an offshore petroleum seismic survey. 209

Figure 3-2. Potential sources of environmental effects from seismic surveys. .210

Figure 3-3. Potential sources of environmental effects exploration drilling.......231

Figure 3-4. Processes for fate of wastes of offshore drilling and production. ...234

Figure 3-5. Example of DREAM model simulation of two sediment stressors..245

Figure 3-6. Example of DREAM model simulation of risk..................................246

Figure 3-7. Example of sediment stressors environmental impact factor 247

Figure 3-8. Concentration of petroleum hydrocarbons in produced water.........264

Figure 3-9. Example of a DREAM simulation of a produced water plume........269

Figure 3-10. Modeled total polycyclic aromatic hydrocarbon concentrations. ..279

Figure 3-11. EROD activity/PAH metabolites cod exposure produced water...280

Figure 3-12. Risk characterization ratios and hazard indices for total PAHs....283

Figure 3-13. Toxicity dose-response produced water on microbial production.285

Figure 4-1. Fishing seasons of moratorium area 315

Figure 4-2. Scallop landings in moratorium area, 2006-2008p 317

Figure 4-3. Scallop total allowable catch in moratorium area............................318

Figure 4-4. Lobster landings in moratorium area, 2006-2008p 320

Figure 4-5. Crab landings in moratorium area, 2006-2008p..............................321

Figure 4-6. Groundfish landings in moratorium area, 2006-2008p 323

Figure 4-7. Groundfish total allowable catch in moratorium area 324

Figure 4-8. Swordfish landings in moratorium area, 2006-2008p 327

Figure 4-9. Tuna landings in moratorium area, 2006-2008p 328

Figure 4-10. Shark landings in moratorium area, 2006-2008p 330

Figure 4-11. Bluefin tuna landings in moratorium area, 2006-2008p 331

Figure 4-12. Herring landings in moratorium area, 2006-2008p 333

Figure 4-13. Offshore petroleum rights in moratorium area 334

Figure 4-14. Shipping routes in moratorium area 336

Figure 4-15. Shipping intensity in moratorium area 337

Figure 4-16. Marine research in moratorium area...338

Figure 4-17. Military exercise areas in moratorium area 340

Figure 4-18. Submarine telecommunication cables in moratorium area 342

Figure 5-1. Landed value by NAFO 5ZE fishery, 1998-2008p 350

Figure 5-2. Scallop landings and landed values NAFO 5ZE, 1998-2008p 352

Figure 5-3. Lobster landings and landed values NAFO 5ZE, 1998-2008p.......354

Figure 5-4. Crab landings and landed values NAFO 5ZE, 1998-2008p 355

Figure 5-5. Groundfish landings and landed values NAFO 5ZE, 1998-2008p .357

Figure 5-6. Swordfish landings and landed value NAFO 5ZE, 1998-2008p 359

Figure 5-7. Tuna landings and landed values NAFO 5ZE, 1998-2008p 361

Figure 5-8. Pelagics landings and landed values NAFO 5ZE, 1998-2008p 363

Figure 5-9. Monthly landed values commercial fisheries NAFO 5ZE, 2008 364

Figure 5-10. Final product value by NAFO 5ZE fishery, 1998-2008p...............368

ABSTRACT

Fisheries and Oceans Canada. 2011. The Marine Environment and Fisheries of Georges Bank, Nova Scotia: Consideration of the Potential Interactions Associated with Offshore Petroleum Activities. Can. Tech. Rep. Fish. Aquat. Sci. 2945: xxxv + 492pp.

Georges Bank is located in the offshore waters between southwest Nova Scotia and Cape Cod. It straddles the Canada-United States maritime boundary, with the northeast portion of the Bank in Canadian waters. In 1988, a moratorium was placed on offshore petroleum activities (i.e. exploration, drilling, and development) on the Canadian portion of the Bank and much of Northeast Channel. In 1999, the moratorium was extended until December 31, 2012, based on the recommendation of a panel review. On May 13, 2010, the governments of Canada and Nova Scotia again extended the moratorium to December 31, 2015. On December 10, 2010, however, the moratorium was extended pursuant to Nova Scotia provincial legislation entitled *Offshore Licensing Policy Act*. This technical report is a compilation of Fisheries and Oceans Canada's (DFO) 'state-of-knowledge' of the marine ecosystem (e.g. oceanography, marine habitat, marine species, and aquatic species at risk), fisheries (including Aboriginal fisheries) and other ocean users of the area, socio-economic profile of the fisheries, and an overview of DFO programs that support oceans management. In addition, the report outlines the potential interactions associated typical petroleum activities that may arise in context of marine ecosystems and fisheries, based on observations from other offshore petroleum development regions. The report does not consider any new knowledge or lessons that may have been learned from the Gulf of Mexico oil spill associated with the April 20, 2010, accident of the Deepwater Horizon, as information regarding any impact of the spill on the marine ecosystem is currently limited. Last, Chapters 2.0 and 3.0 of this report mirror the Canadian Science Advisory Secretariat (CSAS) Research Documents of Kennedy et al. (2011) and Lee et al. (2011), respectively. More details regarding these publications can be found on the CSAS website: www.dfo-mpo.gc.ca/csas.

RÉSUMÉ

Pêches et Océans Canada. 2011. The Marine Environment and Fisheries of Georges Bank, Nova Scotia: Consideration of the Potential Interactions Associated with Offshore Petroleum Activities, Rapport technique canadien des sciences halieutiques et aquatiques n° 2945, xxxv + 492pp.

Le banc Georges se trouve dans les eaux du large situées entre le sud-ouest de la Nouvelle-Écosse et le cap Cod. Il chevauche la frontière maritime entre le Canada et les États-Unis, sa partie nord-est étant dans les eaux canadiennes. En 1988, un moratoire a été décrété sur les activités pétrolières extracôtières (exploration, forage et mise en valeur) dans la partie canadienne du banc et dans une bonne partie du chenal Nord-Est. En 1999, ce moratoire a été prolongé jusqu'au 31 décembre 2012, ainsi que l'avait recommandé une commission d'examen. Le 13 mai 2010, le gouvernement du Canada et celui de la Nouvelle-Écosse ont prolongé de nouveau le moratoire jusqu'au 31 décembre 2015. Toutefois, le 10 décembre 2010, le moratoire a été prolongé en vertu de la loi de la Nouvelle-Écosse intitulée *Offshore Licensing Policy Act*. Le rapport technique qui suit rend compte de l'état actuel des connaissances de Pêches et Océans Canada (le MPO) sur l'écosystème marin (connaissances au sujet des caractéristiques de l'océan, de l'habitat marin, des espèces marines en général et des espèces aquatiques en péril), sur les pêches (y compris les pêches autochtones) ainsi que sur les autres utilisateurs de l'océan dans la région, et il présente un profil socioéconomique des pêches et un aperçu des programmes du MPO qui sous-tendent la gestion des océans. À partir d'observations réalisées dans d'autres régions où le pétrole extracôtier est exploité, le rapport rend compte également des intéractions que peuvent être associées avec les activités pétrolières typiques sur les écosystèmes marins et sur les pêches. En revanche, il ne tient pas compte des nouvelles informations ou des leçons qui pourraient être tirées du déversement de pétrole dans le golfe du Mexique causé par la plateforme Deepwater Horizon le 20 avril 2010, étant donné que l'on dispose encore d'assez peu de données sur les conséquences de ce déversement pour l'écosystème marin. Enfin, les chapitres 2.0 et 3.0 de ce rapport reprennent des éléments des documents de recherche de Kennedy et coll. (2011) et de Lee et coll. (2011) respectivement, publiés sous la coordination du Secrétariat canadien de consultation scientifique (SCCS). Pour plus de détails sur ces publications, on consultera le site Web du SCCS à l'adresse www.dfo-mpo.gc.ca/csas.

EXECUTIVE SUMMARY

Introduction

Georges Bank (the Bank) straddles the Canada–United States maritime boundary on the outer continental shelf between southwest Nova Scotia and Cape Cod, Massachusetts. The Bank is known world-wide as a productive and diverse fishing ground, although it also has significant petroleum resource potential beneath its seafloor. In 1988, a moratorium was placed on offshore petroleum activities (i.e. exploration, drilling, and development) on Georges Bank and much of the Northeast Channel until 2000. In December 1999, the federal Minister of Natural Resources and the provincial Minister responsible for the Nova Scotia Petroleum Directorate accepted a Review Panel's recommendation to extend the moratorium until December 31, 2012. On May 13, 2010, the governments of Canada and Nova Scotia again extended the moratorium to December 31, 2015. On December 10, 2010, however, the moratorium was extended pursuant to Nova Scotia provincial legislation entitled *Offshore Licensing Policy Act*.

This technical report is a compilation of Fisheries and Oceans Canada's (DFO) most up-to-date 'state-of-knowledge' of the Georges Bank marine ecosystem (e.g. oceanography, marine habitat, marine species, and aquatic species at risk), fisheries (including Aboriginal fisheries) and other ocean users of the area, socio-economic profile of the fisheries, and an overview of DFO programs that support oceans management – the report places emphasis on Canada's portion of Georges Bank. In addition, the report outlines the potential interactions associated with typical offshore petroleum activities that may arise in context of marine ecosystems and fisheries, based on observations from other offshore development regions. The report does not consider any new knowledge or lessons that may have been learned from the Gulf of Mexico oil spill associated with the April 20, 2010, accident of the Deepwater Horizon, as information regarding any impact of the spill on the marine ecosystem is currently limited. Last, Chapters 2.0 and 3.0 of this report mirror the Canadian Science Advisory Secretariat (CSAS) Research Documents of Kennedy et al. (2011) and Lee et al. (2011), respectively. More details regarding these publications can be found on the CSAS website: www.dfo-mpo.gc.ca/csas.

Marine Ecosystem and Species

The Georges Bank Moratorium Area is a diverse and productive marine ecosystem that has been the focus of many research initiatives over the past few decades. This has resulted in a good understanding of the individual physical and biological components of the system. There remains, however, many unanswered questions relating to the complex relationships between components, trophic dynamics, the interannual variations of populations, and the linkages with physical and chemical characteristics of the system. Predicting the response of the system to perturbations may be difficult.

The topographic and hydrographic features of the Bank result in high primary production, which in turn fuels high levels of productivity and fish biomass. For example, the strong tidal forces on the Bank, coupled with topographic features, result in the establishment of an anticyclonic gyre that supports a partial retention of planktonic organisms. In addition, the fronts and gyre around the Bank facilitate the upwelling of nutrients onto the Bank and into the photic zone, leading to enhanced plankton production that supports a diverse food web. Perturbations that affect the timing and rate of planktonic production can affect the recruitment success of commercially-important species.

Georges Bank receives cold coastal water from the Gulf of Maine and Scotian Shelf and warm slope water through the Northeast Channel. With influences from both subpolar and subtropical water, the Bank acts as both the northern limit for many warm water species (e.g. bottlenose dolphin and red crab) and the southern limit for many cold water species (e.g. sei whale). This results in a high level of diversity. Georges Bank also serves as a source of organisms for surrounding areas. For instance, strong, episodic forcing (e.g. winter storms) and warm-core ring entrainments can lead to the exchange of water and associated particles with surrounding areas, such as Browns Bank, acting as mechanisms of exchange from the Bank. It is not known, however, what percentage of lobster larvae is retained by the partial gyre of Georges Bank, although pelagic lobster larvae have been observed on the northern edge of the Bank indicating some degree of off-Bank movement.

A distinctive characteristic of the Bank is its populations of bottom-dwelling organisms, which are dominated by large filter feeders (e.g. scallops) that make up three-quarters of the biomass of the large, bottom dwelling organisms found in the area. Georges Bank also provides permanent or temporary habitat for many of the life stages of various fish, invertebrate, seabird, marine mammal, and turtle species, including bluefin tuna, swordfish, shearwater or phalaropes, corals and other benthos, as well as several species that have been listed or are being considered for listing pursuant to the federal *Species at Risk Act*. With the high diversity of organisms, Georges Bank is used year round as a feeding ground, spawning/nursery area, and/or a migration corridor for numerous marine species (see Appendix). For example, leatherback and loggerhead turtles commonly forage on the Bank in the summer and fall, while whales reach peak abundance in the spring and summer. The Bank is an important nursery ground for juvenile cod and haddock, but also acts as a migratory corridor for the North Atlantic Right Whale during its annual migration from wintering areas further south to feeding areas in Canadian waters. Seabirds are also abundant on Georges Bank at all times of the year, although very few birds breed in this area. Last, Georges Bank is an important over-wintering or staging destination for many migratory species, during their northward and southward movements.

Potential Interactions Associated with Offshore Petroleum Activities

Concern over the potential environmental impacts from offshore petroleum exploration and development is largely linked to the possible exposure of marine organisms to seismic noise, operational discharges (e.g. drill wastes, produced water, and other associated wastes), and accidental spills and/or well blowouts. The impacts of seismic noise on invertebrate and fish species include mortality of eggs and larvae, sub-lethal effects, and changes in fish behaviour (e.g. swimming patterns). Mortality likely occurs within a few metres of the sound source, although little is known about whether acute high level sound exposures or chronic low level exposures adversely affect marine organisms at some depth in the water column. There is also conclusive evidence demonstrating the impact of seismic noise on fish behaviour and fisheries catch success.

For marine mammals, although there are no definitive case studies linking mortality resulting from exposure to oil and gas exploration seismic surveys, there is evidence that exposure to seismic sound can result in dispersion and/or temporary displacement of animals. Since behavioral observations of marine mammals are typically variable, some findings are contradictory, and the biological importance of observed effects has not been measured. While impacts to individuals or groups of marine organisms have been observed, there is ongoing debate/investigation regarding the potential for population or ecosystem scale impacts. In addition to sound, a drilling rig and its associated supply vessels generate light during routine operations. While marine mammals may avoid the immediate area around a drill rig due to the unusual and/or increased lights, marine birds and pelagic species, such as squid, may be attracted to the lights of offshore installation or service vessels.

Drilling wastes (i.e. spent drilling mud and well cuttings) are of primary concern during exploration and development drilling operations. In recognition of the results from toxicity studies, current regulatory guidelines in Canada require the recovery and onshore disposal of drill cuttings generated with the use of Oil Based Mud, when possible. If re-injection of drill solids associated with Synthetic Based Mud or Enhanced Mineral Oil Based Muds is not possible, the solids may only be discharged into the marine environment at the drill site following treatment with best available technology. In contrast, low toxicity Water Based Mud is permitted to be discharged into the marine environment. Drilling muds can have both acute (i.e. lethal) and sublethal impacts on marine organisms. Acute effects are predominantly associated with the smothering of slow-moving or sessile benthic organisms near the point of discharge. Sublethal or chronic, long-term impacts such as reduced growth or reproduction may also be associated with sessile benthic organisms if they become exposed to drilling mud components that have settled on the bottom. The magnitude of potential toxic effects is directly linked to exposure time and concentrations (i.e. dosage). Operational models predicting the fate and transport of drilling waste have been coupled with biological effects data to enable the risk assessment of drilling waste disposal.

Under field conditions, drilling muds and cuttings undergo a number of physico-chemical processes in the marine environment following discharge including: (1) advection; (2) dispersion; (3) aggregation; (4) settling; (5) deposition; (6) consolidation; (7) erosion; (8) re-suspension; (9) re-entrainment; and (10) change in bed elevation. Documented results from numerous case studies on water based muds suggest that the degree of impact of drilling fluids and cuttings on benthic and demersal species is highly-dependent on a number of local environmental variables (e.g. depth, current and wave regimes, and substrate type), as well as on the nature and volume of the discharges including cuttings size and location of the outfall in the water column. Numerical models have been developed to improve our knowledge on the probable fate and effect of particles and chemicals associated with drilling wastes discharged into the sea. Integration of risk assessment models with physical transport/fate and effect models will help to evaluate site-specific risks from drilling waste discharges.

There is consistency in the results of environmental effects monitoring) studies from various Canadian East Coast programs despite differences associated with the volumes and type of drilling waste discharges, scale and location of drilling, and variations in monitoring sampling programs. The highest levels of drill waste (sediment and body burden concentrations) were associated with multiple-well, production-based fields that had been operating for several years in the offshore area of Newfoundland. While sampling stations have extended out from the immediate vicinity of platforms to tens of kilometers away for reference sites, study results have demonstrated that changes in the diversity and abundance of benthic organisms have been generally limited to within 1000 metres of the drill site and returned to baseline conditions within 12 months of cessation of drilling discharges. The spatial area for observed biological effects was generally smaller than the area over which drilling muds were detected.

Produced water, a complex mixture of inorganic salts, metals, radioisotopes, production chemicals (e.g. biocides and emulsion breakers), and a wide variety of organic chemicals (e.g. organic acids, petroleum hydrocarbons, and phenols) in both dissolved and particulate phases, represents the largest volume (up to 80%) waste stream in oil and gas production operations. The physical and chemical properties of produced water vary widely depending on the age, depth, and geochemistry of the hydrocarbon-bearing formation, as well as the chemical composition of the oil and gas phases in the reservoir. The chemicals of greatest environmental concern in produced water, because of their potential for bioaccumulation and toxicity, are metals and hydrocarbons. While their concentration in the produced water stream is generally below the effects threshold, in some regions there has been concern that highly-alkylated phenols (octyl- and nonyl-phenols), which are well-known endocrine disruptors and some toxic production treatment chemicals, may cause localized effects. If water depths are shallow, some metals (e.g. barium, iron, and manganese) and higher molecular weight aromatic and saturated hydrocarbons may accumulate in sediments near produced water discharges, possibly harming bottom living biological communities.

In Canada, the formulation of regulatory guideline values for produced water discharge is an adaptive process that promotes the development of improved EEM programs that take into consideration the level of environmental risk, Best Available Technology for mitigation measures, and socio-economic benefits. The current regulatory guidelines for produced water discharge in Canada (i.e. Offshore Waste Treatment Guidelines) are based on petroleum hydrocarbon content. Treatment of produced water for regulatory compliance before ocean discharge removes solids and non-aqueous liquids from the waste water, including dispersed oil, suspended solids, scales, and bacterial particles, as well as corrosive gases such as carbon dioxide and hydrogen sulphide. Existing clean-up protocols for produced water are effective in removing volatile compounds and dispersed oil from the produced water, but not the dissolved organic and inorganic fractions. Treated produced waters on offshore platforms are typically discharged below the sea surface at a depth from 10-100 metres.

The various models used to predict the fate of produced water (e.g. plume dispersion models and chemical fate/transport models) differ in specific details, but all predict a rapid initial dilution of discharges by 30- to 100-fold in the first few tens of meters of the discharge, followed by a slower rate of dilution at greater distances. Factors that affect the rate of dilution of produced water include discharge rate and height above or below the sea surface, ambient current speed, turbulent mixing regime, water column stratification, water depth, and differences in density (as determined by temperature and total dissolved solids concentration) and chemical composition between the produced water and ambient seawater. Based on the chemical composition of treated produced water and predicted dispersion rates for potential sites of concern, it is expected that toxicity threshold limits for acute effects are not likely to occur beyond the immediate vicinity of the discharge pipe for offshore platforms located on the East Coast of Canada, due to natural dispersion processes driven by tides and currents. Over the 15 to 20 year life-span of a typical offshore platform, however, there is concern that continual long-term chronic exposures to produced water discharges may cause sub-lethal changes in marine organisms.

It has recently been suggested that the toxicity of produced water may diminish over time following its discharge, due to natural chemical kinetic reactions that occur following its release (in an anoxic state) into the open ocean. Due to the differing rates of degradation of the multiple toxic components in produced water and the variation of ecosystem effects resulting from differences in toxicity, modeling efforts have been employed to try to account for the variations and determine the general ecological risks associated with produced water discharge overtime. The accuracy of contaminant risk assessment models is dependent on the identification and quantification of the various chemicals that induce the toxic effects. Additional information on the toxicity of produced water components will improve the accuracy of the Environmental Impact Factor model currently used for risk assessment of produced water discharges. In regard to other wastes, the Offshore Waste Treatment Guidelines, Nova Scotia Offshore Petroleum Drilling and Production Regulations, and domestic waste treatment technologies recommended by the Department of the Environment are in place to mitigate the potential risks associated with the disposal of domestic waste from offshore facilities. Furthermore, under Canadian drilling regulations, solid operational debris (e.g. anchors, chains, etc.) on the sea floor is to be removed when a well is abandoned.

For offshore oil and gas exploration and production activities, the risk and consequence of oil spills is of the greatest environmental concern. From a socioeconomic perspective, however, tainting and contamination of fisheries resources leading to closures would be of greatest concern. Although there is a low probability of occurrence, spills, blowouts, and malfunctions can result in the release of liquid and gaseous hydrocarbons. Blowouts occur when operators are unable to control the flow of oil or gas and it is released into the atmosphere or surrounding water. Oil spills other than from blowouts can occur during drilling and production activities. These include spills of diesel oil or lubricating oil for operations on the platforms, as well as spills from transfer and transport operations. In general, spills are usually small and have minimal/negligible environmental impact. Larger spills, however, can occur. In addition to accidental releases, a significant amount of crude oil, estimated between 4.2-14 million barrels, is discharged each year from natural seepage. Natural seepage accounts for the largest, cumulative source of oil that enters the ocean. In the North Atlantic, the occurrence of natural oil seeps has been well documented from the Canadian Arctic to the Gulf of Mexico, including the Georges Bank region.

Scientific studies on the transport and effects of petroleum hydrocarbons (i.e. gas, gas condensate, and/or oil) from spills and blowouts have been ongoing for decades. In the event of an accidental release of gas, it is anticipated that much of it would be rapidly dissipated into the atmosphere with the assistance of the wind. While a large fraction of gas condensate would evaporate, some components such as benzenes and naphthalenes may elicit an acute toxic effect near the point of release depending on duration, timing, and location of the event. The release of crude oil may result in a surface slick that eventually becomes entrained in the water column and/or becomes incorporated into sediments. Oil concentrations on the order of 100 parts per billion have been demonstrated to cause both lethal and sublethal effects on planktonic organisms in laboratory studies. It has been difficult, however, to demonstrate that either major spills or chronic oil input have any irreversible impacts on marine planktonic communities.

For fish and marine invertebrates, the major concern is a spill incident that coincides in the time and place of a fish spawning event. Benthic organisms, such as scallops, are also susceptible to exposure. Residual hydrocarbons may not persist in surficial sediments over an extended period, due to strong currents that could continually disperse and transport fine sediment particles over a wider area and into deep waters. To predict spill trajectories, a number of oil spill models and operational tools (e.g. tracker buoys) covering a range of capabilities, from simple trajectory models to 3D trajectory and fate models, are in use in the world today. The application of predictive models is also used to support risk assessment studies and operations to provide critical guidance for contingency planning as well as clean-up operations.

In the offshore of Nova Scotia, individual operators have the responsibility to implement a corporate Emergency and Oil Spill Response Plan approved by the Canada-Nova Scotia Offshore Petroleum Board (CNSOPB) that includes routine spill response exercises. Physical containment and recovery of bulk oil is generally considered the first line of defense following a spill. The effectiveness of physical recovery processes for oil spilled in the open-sea is limited by logistical constraints (e.g. the spreading rate of oil spills and operational limitations for containment booms), but mostly by weather (e.g. sea state) which is the largest limiting factor to containment and recovery. As a result, there is a renewed interest regarding the application of chemical dispersants, which promote the transfer of oil on the surface into the water column by promoting the generation of oil droplets. This countermeasure technique is based on the premise of promoting the dilution of oil to concentrations below toxicity threshold limits for water-borne organisms. Furthermore, the dispersion of oil into the water column will enhance the biodegradation rates of residual hydrocarbon compounds.

Decisions on chemical oil dispersant use should include a net benefit analysis. While the application of dispersants would reduce the contact between seabirds and surface oil slicks, and the probability of oil impacting shoreline environments, there is concern that they may also increase the bioavailability of toxic components to pelagic organisms. With advances in scientific knowledge, improvements are continually being made in the areas of prevention, environmental effects monitoring, risk assessment, mitigation, and remediation of potential impacts to the marine environment associated with offshore petroleum development and production activities.

Fisheries and Other Ocean Users

The predominant users of the Georges Bank moratorium area are the fisheries. In the region, 16 First Nations and the Native Council of Nova Scotia are fishery licence holders, which may afford rights to fish on Georges Bank for Food, Social, and Ceremonial purposes and commercial communal fishing. The Government of Canada may be required to consult Aboriginal groups regarding any potential decision that may affect their fishing activity and, where appropriate, accommodate their interests (Government of Canada, 2011). In addition, 1783 active commercial fishing licences are currently issued that permit fishing in the region. Fisheries of the area include: shellfish fisheries (i.e. sea scallop, lobster, and crab); groundfish fisheries (i.e. cod, haddock, and yellowtail flounder); and pelagics fisheries (i.e. swordfish, tuna, herring, and other pelagic species such as mahi mahi and shark).

Other potential ocean users of the moratorium area include maritime transportation, scientific research, telecommunications, and the military. Offshore petroleum rights also exist in the moratorium area. Before offshore petroleum exploration and development activities can commence on lands covered by a permit, the permit must be replaced by a negotiated exploration licence. Due to the moratorium, the time within which an exploration licence must be negotiated has been extended by the CNSOPB.

Potential interactions of the offshore petroleum industry with the fishing industry include: 1) access; 2) vessel and gear conflicts; and 3) accidental spills. Hindered access occurs when an activity occupying a marine space influences how another ocean user may use that space. Hindered access to marine space due to offshore petroleum activities are separated into short-term (i.e. days to months) due to seismic and drilling programs and long-term (i.e. years to decades) due to production. The duration and scale of influence on access of the fishing industry depends on the nature of an offshore petroleum activity and the number of activities occurring at a given time. Vessel and gear interactions may also result from an overlapping occurrence of fishing and offshore petroleum activities. Last, there may be short-term and long-term effects to the fishing industry (including associated industries and communities) in the event of large accidental petroleum spills.

Although the potential effects on the fishery from large scale offshore petroleum spills are great, globally, the incident rate of large scale spills associated with offshore petroleum activity is low. In the presence of a large spill, in addition to potential impacts to the marine ecosystem, negative public perception of fishery resources from a market perspective may result. To mitigate potential interactions of offshore petroleum activities, the industry operating in other regions of the Nova Scotia offshore abides by several regulations, standards, and best practices. Last, it should be noted that other ocean users such as the fishing industry may also exhibit interactions that influence the offshore petroleum industry.

Socio-economics of Fisheries

In 2008, eight vessels fished six Aboriginal licences in NAFO Zone 5ZE (5ZE most closely reflects the fisheries of the moratorium area). The vessels combined for a total landed value of approximately $1.73 million. The landings consisted primarily of groundfish, which exhibited a total landed value of approximately $1.68 million. Other species that were caught included swordfish, tuna, and shark. The vessels fished eight months of the year. The dependency of Aboriginal licence holders on 5ZE fisheries varied from approximately 2–22% of their total catch for the year, with the average value being 8.8%. The eight vessels landed primarily in Yarmouth County, Nova Scotia.

The annual total landed value of all fisheries operating in 5ZE has seen significant variation over the past decade. Since 2005, however, the total annual landed value of all fisheries has been increasing, with preliminary data for 2008 indicating a total landed value of more than $105 million (up from approximately $84 million in 2007). The scallop fishery contributed the largest portion of the annual total landed value from 5ZE and, on average, has accounted for 77% of the total value over the past decade. Other important fisheries of 5ZE include lobster, groundfish, and swordfish. In 2008, fishing activity in 5ZE occurred year round, with nearly two-thirds of the total landed value being caught from May to September.

The fisheries of Georges Bank contribute to the economy of Nova Scotia. In 2008, 217 fishing vessels operated in 5ZE, with most of the vessels landing at ports in Lunenburg, Queens, Shelburne, Yarmouth, and Digby counties of southwest Nova Scotia. Landings from 5ZE represented approximately one-quarter of the total value landed in those counties. In addition to fishing, it is estimated that fish processing contributes an additional 60% to the total value of 5ZE fishery landings. Preliminary data for 2008 indicated a final product value (i.e. combined value of fishery landings and additional fish processing value) for 5ZE landings of approximately $168 million, compared to $105 million for the fishery landed values alone.

Fishing vessels operating in 5ZE in 2008 provided an estimated 1059 jobs for individuals working on the vessels at some point during the year. Just under half of the employed positions were associated with shellfish fishery vessels. The total personal income earned by the individuals is estimated to be $43.1 million. Furthermore, processing of 5ZE fishery landings supported an estimated 956 full-time equivalent employment positions during the peak processing months of 2008, providing an estimated $9.1 million in total personal income throughout the year.

Oceans, Fisheries, Species at Risk, and Emergency Preparedness Management

Fisheries and Oceans Canada and the Canadian Coast Guard deliver programs and services pursuant to the *Oceans Act*, *Fisheries Act*, *Species at Risk Act*, *Canada Shipping Act*, and *Constitution Act*. Management decisions made by the department may also be subject to the *Canadian Environmental Assessment Act* and the Cabinet Directive on the Environmental Assessment of Policy, Plan and

Program Proposals for Strategic Environmental Assessment. Departmental programs and services support sustainable oceans management that is guided by a precautionary approach, ecosystem approach, and integrated approach to decision making.

A precautionary approach to management and planning errs on the side of caution in decision making, in the absence of scientific certainty. The absence of scientific certainty, however, shall not halt economic development provided that the risks associated with proceeding are evaluated prior to decision making (Government of Canada, 2003). An ecosystem approach places the ecosystem at the forefront of decision-making in managing a resource. An integrated approach coordinates management between stakeholders of all human activities in a management area, so that human-ecosystem and human-human conflicts can be anticipated, prevented, and minimized.

The Oceans Management Program promotes integrated management through the Eastern Scotian Shelf Integrated Management Initiative. It also promotes marine conservation through its Marine Protected Areas, Coral Conservation Areas, and Whale Conservation Areas, as well as its conservation planning. The Habitat Management Program supports fish and fish habitat management through the environmental assessment of marine project proposals, as well as follow-up compliance and environmental effects monitoring. The Fisheries Management Program is undergoing a Fisheries Management Renewal, in support of sustainable fisheries and aquaculture management. Fisheries Management Renewal is a package of program renewal undertakings that promote predictability, stability and transparency, and strong and healthy fisheries resources. The Species at Risk Program supports the protection and recovery of aquatic species at risk, including the protection of habitat that supports at risk aquatic species from further harm, disruption, and destruction.

Last, in support of marine emergency preparedness, the Canadian Coast Guard Marine Spill Contingency Plan defines the scope and framework within which the Coast Guard is prepared for and responds to a marine enviornmental emergency. The department also supports response to an environmental emergency through participation on Environment Canada's Regional Environmental Emergency Team.

1.0 INTRODUCTION

1.1 INTRODUCTION

Georges Bank (the Bank) is an offshore bank located on the outer continental shelf between southwest Nova Scotia and Cape Cod, Massachusetts (Figure 1-1). It straddles the Canada–United States maritime boundary and the northeast portion of the Bank is in Canadian waters. The Bank is a unique marine ecosystem that exhibits exceptional levels of biological productivity and biodiversity. It is known world-wide as a productive and diverse fishing ground that supports several economically-valuable commercial fisheries in the region. The Bank also has significant petroleum resource potential beneath its seafloor. On the Canadian portion of Georges Bank there are an estimated 60 million barrels of oil and 1.3 trillion cubic feet of natural gas, although exact amounts remain uncertain (Procter et al., 1984).

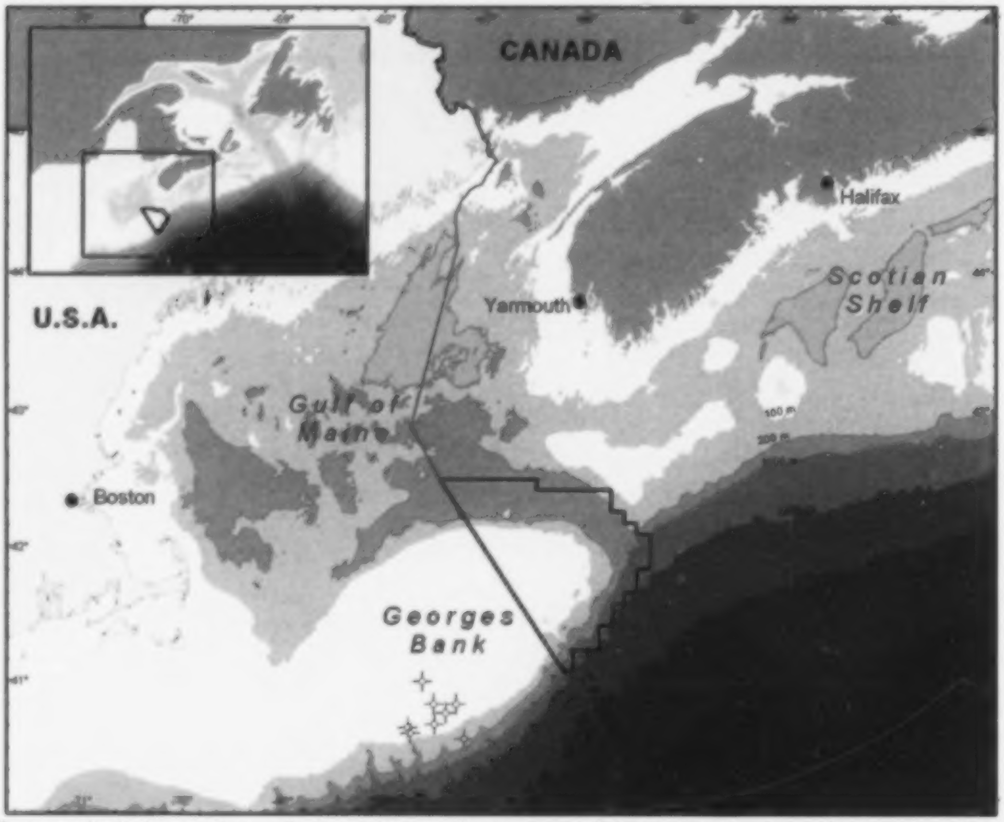


Figure 1-1. Location of the moratorium area (black line) placed on petroleum activity (i.e. exploration, drilling, and development) on Georges Bank and much of the Northeast Channel in the offshore of Nova Scotia. The grey line represents the boundary of Canada's exclusive economic zone. The black circles with tick marks represent the locations of eight petroleum exploratory wells drilled on the U.S. portion of Georges Bank.

Georges Bank has been an area of interest for offshore petroleum exploration and development for more than four decades (NRCan and NSPD, 1999). In 1964, the Government of Canada issued its first permit for offshore petroleum exploration on the Bank, which signified Canada's claim to territorial rights in the region. In 1969, the United States informed Canada that it too was claiming territorial rights on Georges Bank and proposed a moratorium on offshore petroleum drilling on the Bank in the interim. In 1976-1977, however, the United States permitted the drilling of two offshore petroleum exploratory wells on the undisputed American portion of the Bank. This was followed by an additional six wells drilled between 1981 and 1982. The eight wells did not exhibit any offshore petroleum resource potential (Figure 1-1). Figure 1-2 outlines select submarine features associated with Georges Bank and the surrounding region (may be referred to later in this report).

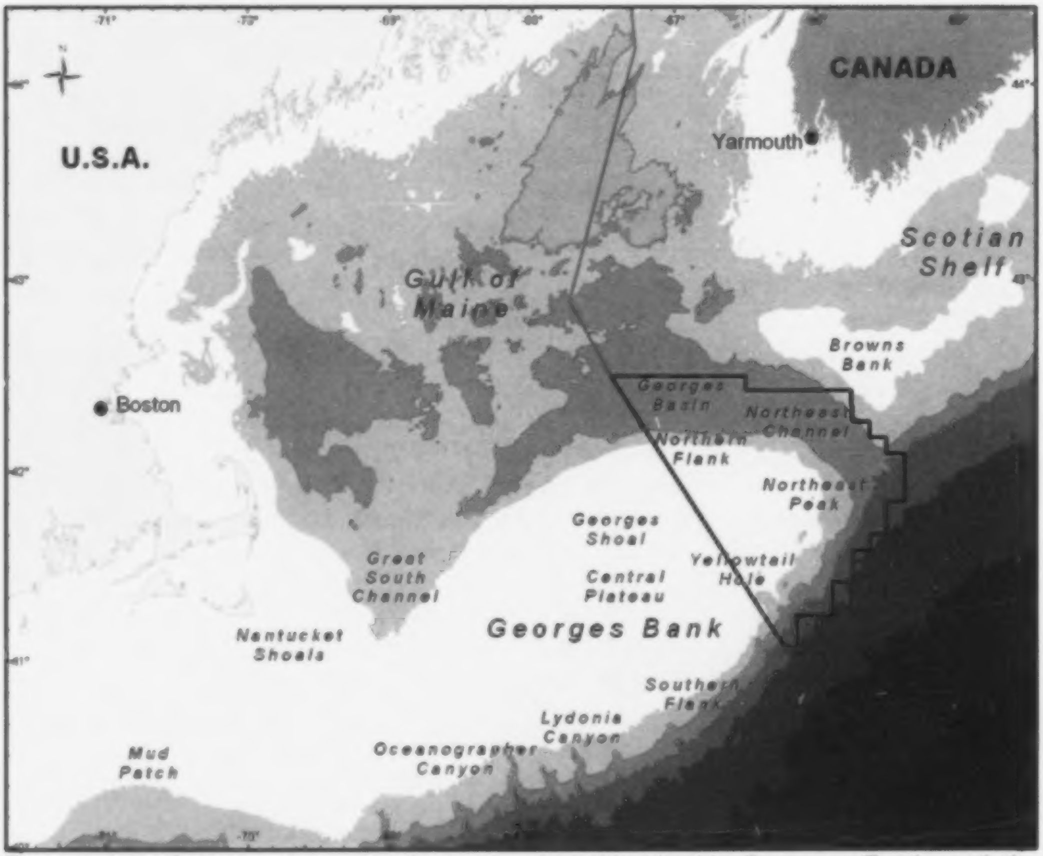

CANADA
Yarmouth
U.S.A.
Scotian Shelf
Gulf of Maine
Browns Bank
Boston
Georges Basin
Northeast Channel
Northern Flank
Northeast Peak
Georges Shoal
Yellowtail Hole
Great South Channel
Central Plateau
Georges Bank
Nantucket Shoals
Southern Flank
Lydonia Canyon
Oceanographer Canyon
Mud Patch

Figure 1-2. Select submarine features associated with Georges Bank and the surrounding region.

In 1984, the Canada-United States boundary dispute was settled by the International Court of Justice at The Hague, Netherlands (NRCan and NSPD, 1999). The decision gave Canada jurisdiction over the northeast portion of

Georges Bank. In 1986, consultation regarding proposed offshore petroleum exploration on Canada's portion of the Bank led to opposition by local fishing interests and residents and, in response, the Government of Canada and the Province of Nova Scotia enacted the *Canada-Nova Scotia Offshore Petroleum Accord Acts* in 1988. The legislation placed a moratorium on offshore petroleum activities on the Canadian portion of Georges Bank and the adjacent Northeast Channel area (Figure 1-1) until January 1, 2000 (NRCan and NSPD, 1999).

In 1996, the federal Minister of Natural Resources and provincial Minister of Natural Resources (Nova Scotia) appointed a three person panel to undertake public consultation and review of the moratorium. Based on input from the review panel, the federal Minister of Natural Resources and provincial Minister responsible for the Nova Scotia Petroleum Directorate decided to extend the moratorium on offshore petroleum exploration on Georges Bank and much of Northeast Channel until December 31, 2012. On May 13, 2010, the governments of Canada and Nova Scotia again extended the moratorium to December 31, 2015. On December 10, 2010, however, the moratorium was extended indefinitely pursuant to Nova Scotia provincial legislation entitled *Offshore Licensing Policy Act*. In the United States, President Obama announced on March 31, 2010, that offshore petroleum activities in the U.S. North Atlantic region, which includes the U.S. portion of Georges Bank, would not be considered for leasing until 2017. The exclusion of the region acts, in essence, as a de facto moratorium on petroleum exploration and development throughout the U.S. North Atlantic offshore region.

This technical report is a compilation of Fisheries and Oceans Canada's (DFO) most up-to-date 'state-of-knowledge' of the Georges Bank marine ecosystem (e.g. oceanography, marine habitat, marine species, and aquatic species at risk), fisheries (including Aboriginal fisheries) and other ocean users of the area, socio-economic profile of the fisheries, and an overview of DFO programs that support oceans management – the report places emphasis on Canada's portion of Georges Bank. In addition, the report outlines the potential interactions associated with typical offshore petroleum activities that may arise in context of marine ecosystems and fisheries, based on observations from other offshore development regions. The intent is that the report will provide a background of known information and data gaps in regard to the Georges Bank moratorium area. The report, however, does not consider any new knowledge or lessons that may have been learned from the Gulf of Mexico oil spill associated with the April 20, 2010, accident of the Deepwater Horizon.

Fisheries and Oceans Canada is the lead federal government authority that oversees the management of Canada's fisheries and oceans. It maintains its regulatory obligations regarding the conservation and protection of fish and fish habitat. The DFO Science Branch undertakes research in support of improved understanding of the marine ecosystem and its Centre for Offshore Oil, Gas and Energy Research (COOGER) coordinates a national research program into the potential influence of offshore petroleum and ocean renewable energy activities on the marine environment. In support of the decision regarding the moratorium, DFO made its expertise and advice available to the federal Minister of Natural Resources. This report reflects part of that commitment. Last, Chapters 2.0 and 3.0 of this report mirror the Canadian Science Advisory Secretariat (CSAS) Research Documents of Kennedy et al. (2011) and Lee et al. (2011), respectively. More details regarding these publications can be found on the CSAS website: www.dfo-mpo.gc.ca/csas.

2.0 MARINE ECOSYSTEM

2.1 GENERAL TOPOGRAPHY

The top of Georges Bank has an area of approximately 28,800 kilometres-squared (km^2) above the 100 metre (m) isobath, while the top and the sides of the Bank have an area of approximately 43,000 km^2 above the 200 m isobath (Collie et al., 2009). The Canadian portion of Georges Bank, sometimes referred to as the Northeast Peak, accounts for less than 50% of its total area (approximately 7000 km^2). Georges Bank is connected to the deep ocean through a series of submarine canyons on the southern edge (Figure 2-1). The Canadian moratorium area covers approximately 15,000 km^2 and includes both Canada's portion of Georges Bank and much of the Northeast Channel.

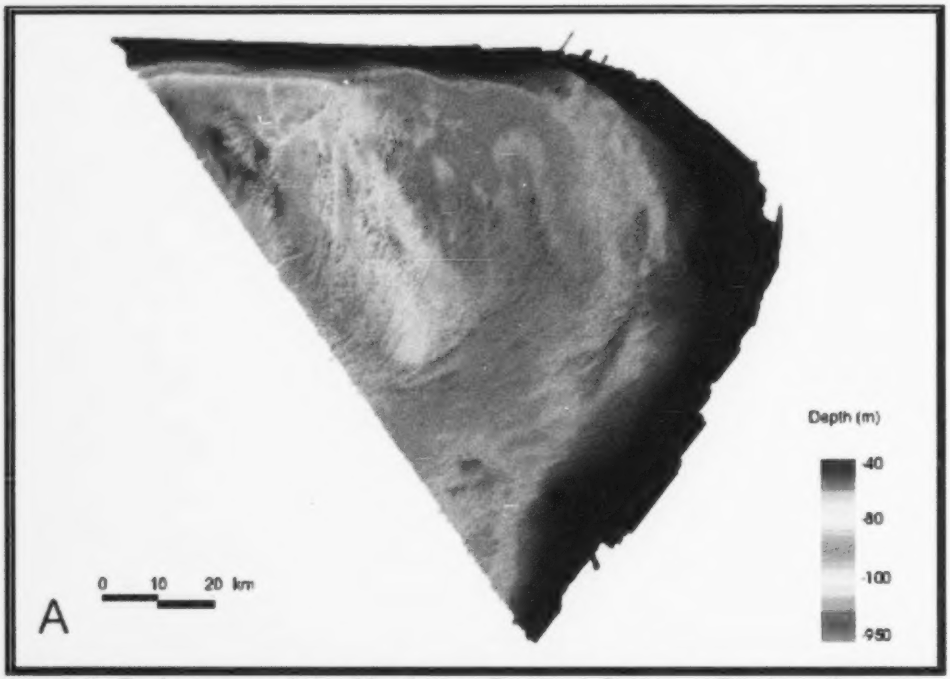


Figure 2-1. Bathymetry of the Northeast Peak of Georges Bank and surrounding waters collected using a digital multibeam bathymetric sounding approach (Kostylev et al., 2005). Depth is in metres (m) below mean surface.

Georges Bank is bounded on the west by the Great South Channel, with a depth of 70 m, on the north and east by the Gulf of Maine and the Northeast Channel, with depths near 300 m, and on the south by the continental slope (Incze, 1998; GOMA, 2010) (Figure 1-1). Rugged canyons, which range by as much as 1 kilometre (km) in depth, incise the southern edge of the Bank. The sides of the Northeast Peak are steeply sloped, exhibiting changes in water depth of more than 100 m over less than 10 km distance. The deep offshore channels that run along the ends of the Bank (i.e. Northeast Channel and Great South Channel) provide pathways for significant subsurface flow into and out of the Gulf of Maine, respectively. The average water depth across the top of the Bank is 75 m (Incze, 1998; GOMA, 2010), although this varies from an area of shallow shoals on the United States portion of the Bank to deeper waters between 60-100 m depth on the Northeast Peak.

2.2 CIRCULATION, HYDROGRAPHIC STRUCTURE, AND MIXING

The movement of water and marine particles (e.g. sediment or organic particles such as phytoplankton) on Georges Bank is primarily driven by tidal currents, but also by wind and variation in water density (Butman et al., 1987; Flagg, 1987; Naimie et al., 1994). The movement of water resulting from these forces is mediated by the region's bottom topography. The location of Georges Bank at the mouth of the Gulf of Maine/Bay of Fundy tidal system, coupled with its shallow depth, gives rise to strong tidal currents. The strongest currents are associated with the semidiurnal M2 tide, which exhibits a period of 12.4 hours. This is near a resonance condition in the Gulf of Maine and Bay of Fundy (Garrett, 1972).

Tidal current velocities range from approximately 0.2 metres per second ($m\ s^{-1}$) in deeper water around the perimeter of the Bank to more than 1.0 $m\ s^{-1}$ on the top of the Bank (i.e. the central plateau) (Moody et al., 1984; Xue et al., 2000). Strong, spatially-uniform M2 tidal currents cause water parcels to undergo semi-daily elliptical excursions, with major axes ranging from a few kilometers in deeper water to over 15 km on the central plateau (Figure 2-2). As a result, to first order, any buoyant or neutrally-buoyant material that is released into the water column from a fixed point on the Bank is carried, within hours, over distances comparable to that of the local tidal ellipses (in reality the pathways are complicated by non-uniformity of the M2 field and by other constituents of the flow field). Similarly, any material on the sea floor is susceptible to the movement of large volumes of sea water, as well as associated physical forces such as shear stress.

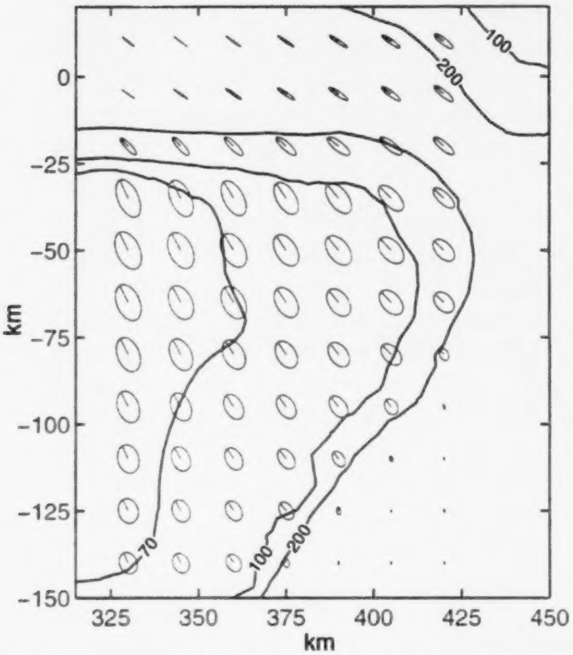


Figure 2-2. M2 tidal excursions of Northeast Peak of Georges Bank based on depth-averaged tidal velocities estimated from the 3-D circulation model of Naimie (1996). Tidal ellipses, traced by the tip of the tidal velocity vector over one cycle, are drawn to the scale of associated water parcel excursions (i.e. small ellipses). The radial lines indicate common phase (i.e. small lines inside the ellipses). Bathymetry is in metres (m) below mean sea surface.

The general circulation pattern on Georges Bank is a partial, anticyclonic gyre (i.e. water rotates in a clockwise direction around the Bank) (Figure 2-3, upper panel). This persistent year-round circulation is associated primarily with non-linear interactions of the tidal currents over the Bank's topography. Water velocities associated with the gyre are typically 0.1-0.2 m s^{-1}, but increase to 0.2-0.4 m s^{-1} along the Bank's northern edge (Butman et al., 1987; Naimie et al., 1994; Naimie, 1996). Higher water velocities usually occur in the summer season. This seasonal intensification is primarily associated with horizontal density gradients in the frontal system. The mean flows associated with the gyre are generally strongest in the upper half of the water column, and significantly decrease towards the seafloor.

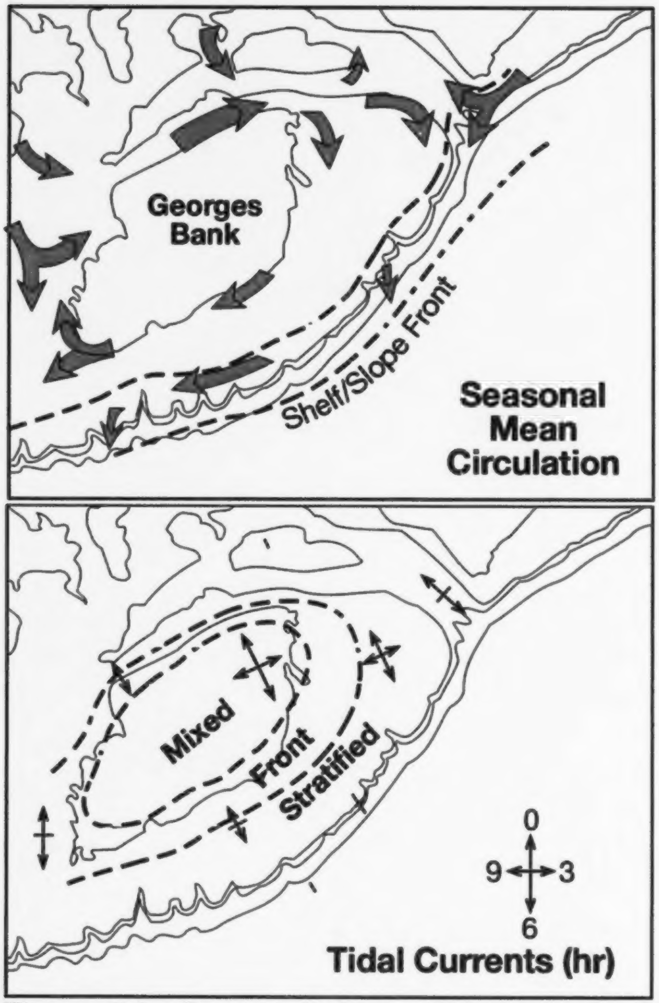


Figure 2-3. General hydrographic structure and seasonal mean circulation pattern observed on Georges Bank. The upper panel exhibits the mean seasonal circulation (arrows) and the extent of the shelf water/slope water front observed throughout the year (dashed lines). The lower panel exhibits tidal current patterns (arrows) and the extent of the seasonal tidal-mixing front observed during peak summer stratification (dashed lines).

The gyre is described as 'partial' because the recirculation of the flow around the Bank has a strong seasonal dependence and is subject to disruption by energetic transient events, such as storms and the impingement of warm core rings (WCRs) from the Gulf Stream on the offshore edge of the Bank. The seasonal behaviour of the gyre is produced by the onset of stratified conditions in the summer (July-October) and the establishment of the tidal mixing front, which bounds the well-mixed water on the top of the Bank (Figure 2-3, lower panel). During summer, near-surface recirculation is established with the setting up of northward flow in the Great South Channel, which persists until winter approaches in November (Namie et al., 2001). The minimum summer recirculation time is estimated to be 40 days. Outside the summer season (e.g. March-June), recirculations are rare, but when they do occur, they generally require much longer periods to complete the circuit (i.e. 80-130 days).

At all times of the year, the gyre tends to be 'leaky', in the sense that strong, episodic forcing (e.g. by winter storms) produces a significant exchange of water and associated particles with the surrounding waters of Browns Bank, Gulf of Maine, and the adjacent continental slope (Butman and Beardsley, 1987) (Figures 2-4 and 2-8). One of the most effective of these mechanisms is the impingement of large-scale (i.e. 100-200 km cross-sectional distance) WCRs, which are isolated eddies that 'pinch off' of the Gulf Stream and move into the slope water regime that lies between the Gulf Stream and the continental shelf (Smith, 1978). In the region between 60° and 70°W, WCR formation is thought to be induced by the Gulf Stream's encounter with the New England seamounts that cause meanders that rapidly grow to ultimately form a WCR. The frequency of WCR events is estimated to be 5-6 per year in the zone 60-70°W (Lai and Richardson, 1977; Smith, 1978). Once formed, WCRs generally drift westward along the continental slope, impinging frequently on the edge of the shelf where they can exchange large volumes of mass, heat, and salt. After a period on the order of 6 months to one year, WCRs tend to dissipate or are reabsorbed by the Gulf Stream in the western end of the slope water domain.

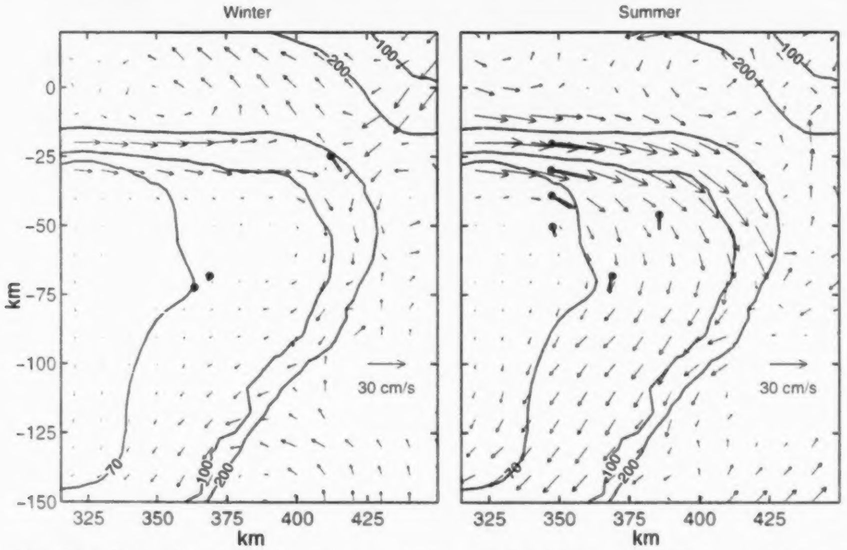


Figure 2-4. Modeled mean water velocities at 20 m below surface on the Northeast Peak of Georges Bank for winter (January-February) and summer (September-October) seasons. Model estimates are from the 3-D circulation model of Naimie (1995). The magnitude and direction of flow are represented by the length and orientation of the thin vector arrows. Bathymetry is in metres (m) below mean sea surface. Observed seasonal mean water velocities from moored measurements at 10-50 m water depth are represented by the thick vector arrows. Observations are from the July to August summer period.

Vertical mixing, bottom stress (and hence sediment transport), and the generation of seasonal mean currents observed on Georges Bank are primarily due to tides. Energetic vertical mixing associated with strong tidal currents observed on the Bank's central plateau (Garrett et al., 1978) results in the uniform distribution of temperature, salinity, and density throughout the water column in water depths less than approximately 60 m (Figure 2-3, lower panel, 'Mixed'). The largest variation in hydrographic properties is observed in the persistent shelf-edge front between cooler and fresher shelf waters and the warmer and more saltier slope waters (Flagg, 1987) (Figure 2-3, upper panel, 'Shelf/Slope Front').

In the winter, increased wind-driven mixing coupled with cooling surface waters results in well-mixed waters observed throughout the water column to depths of 100 m (Figure 2-5). The hydrographic properties (i.e. temperature, salinity, and density) of these waters become similar to those observed in ambient shelf regions. In the spring, seasonal heating of surface waters results in the development of strong upper ocean stratification around the Bank, with a seasonal tidal-mixing front observed over the Bank's edges (i.e. a transition zone between mixed and stratified waters) (Page et al., 2001) (Figure 2-3, lower panel, 'Front'). The interannual variability of the stratification of water above the sides of the Bank can be large (Bisagni, 2000). In addition, the vertical structure associated with the seasonal frontal system can be complex, with internal waves, small scale turbulence, and surface convergence. The seasonal progression of the front is shown by the density difference between surface waters and waters at 50 m depth, or the bottom if shallower than 50 m, over the course of the six bimonthly periods (Figure 2-5). Figure 2-5 indicates that the front is most intense in the summer, when its width varies from 15-20 km over the Bank's northern edge and up to 40-50 km over the Bank's Northeast Peak. Furthermore, the increasing speed of water as it spreads across the Northeast Peak, especially in the summer (Figure 2-4), is associated with the seasonal on-bank migration of the tidal front.

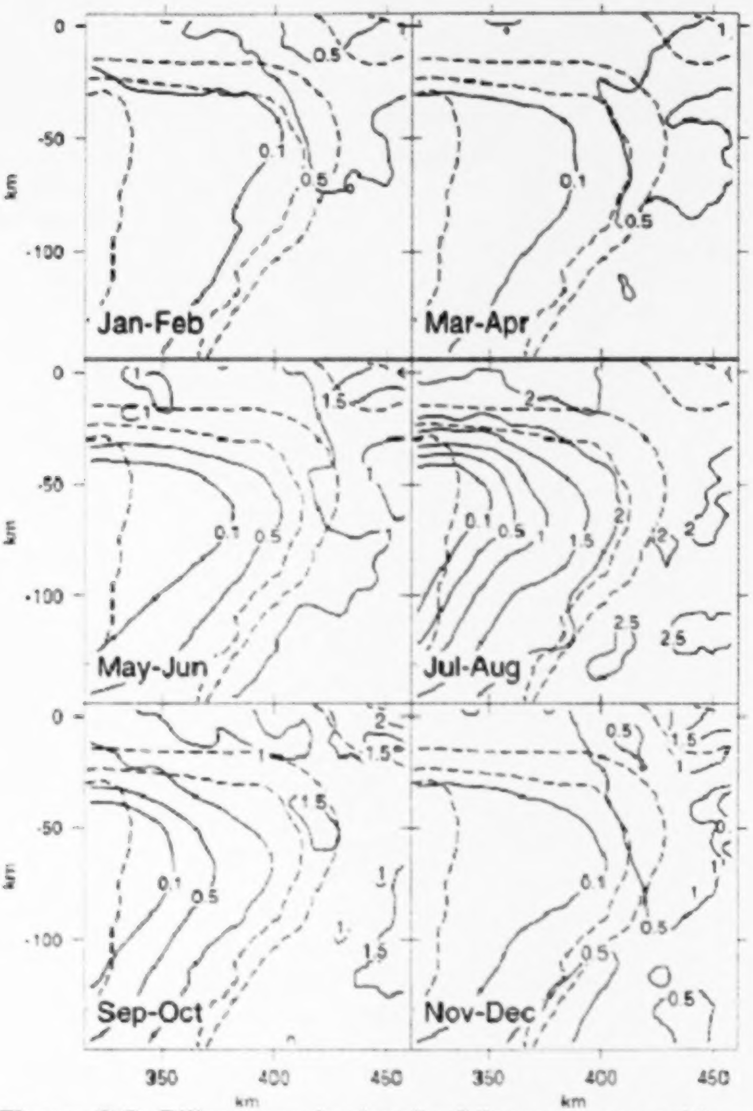


Figure 2-5. Differences in density (kilograms per cubic-metre, kg m^{-3}) between surface waters and waters at 50 m depth, or the bottom if shallower than 50 m, on the Northeast Peak of Georges Bank (solid lines represent density differences in 0, units). Estimates are for six bimonthly periods of a modeled year. Differences were estimated from the 3-D circulation model of Naimie (1995) using historical input data (Hannah et al., 1996). The dashed lines represent the 60, 100, and 200 m isobaths observed on the Bank, similar to those observed in Figure 2-4 above.

Frontal processes are important factors in both the retentive and dispersive characteristics of the Northeast Peak during much of the year (i.e. spring to fall). They have been the focus of much DFO research in the 1990s, which has improved the quantitative description and understanding of hydrographic structure, vertical mixing, internal waves, circulation, surface convergence, and dispersion in the frontal zone of Georges Bank (e.g. Loder et al., 1993). In particular, new field measurements have revealed the structure and extent of small-scale and intermediate-scale frontal zone features, illustrated schematically in Figure 2-6. The Northeast Peak frontal zone can be conceptualized as a hybrid, exhibiting characteristics of both tidal-mixing and bank-edge fronts (Loder et al., 1992).

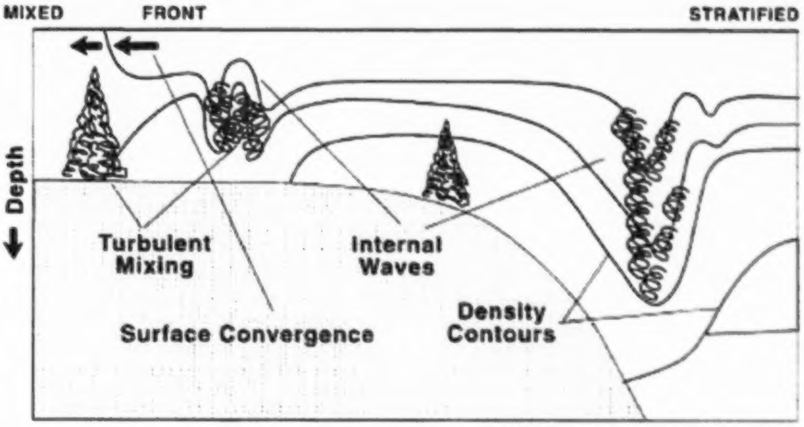


Figure 2-6. Schematic representation of the vertical structure associated with the seasonal frontal system over the northern edge of the Northeast Peak of Georges Bank. The structure of internal waves, small-scale turbulence, and surface convergence are represented.

The combined effect of the seasonal mean circulation pattern (i.e. partial gyre), tidal currents, and the near-surface convergence in the frontal zone are illustrated by the movement of three near-surface drifters at 20 m depth below the surface, deployed on the northern part of Georges Bank on July 27, 1989 (Figure 2-7). The drifters moved in close proximity to each other following release and circulated eastward in a spiral pattern due to the tidal ellipses and frontal-zone jet observed in this region of the Bank. Over the two day deployment period the drifters traveled more than 100 km, but they were recovered only approximately 20 km from their release points in a straight line distance. Upon recovery, the drifters were less than 2 km apart. The trajectory data illustrated in Figure 2-7 was obtained in the absence of strong weather systems or other short-term perturbations that typically affect the average current patterns of the Bank.

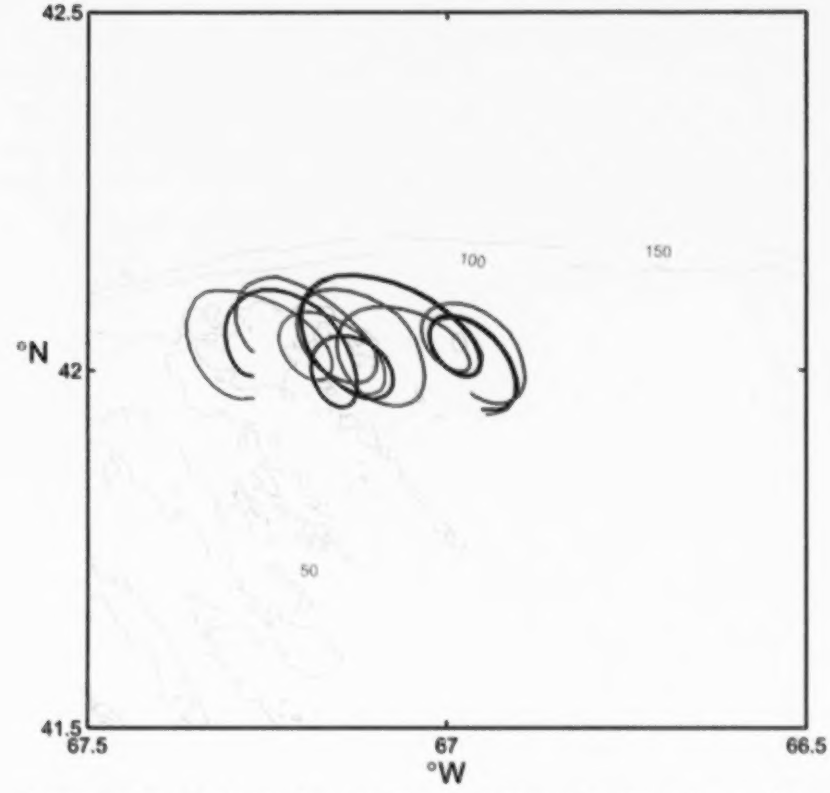


Figure 2-7. Trajectories of three drifters deployed on the northern edge of Georges Bank on July 27, 1989. Over the two day deployment period the drifters traveled more than 100 km, but were recovered only approximately 20 km from their release points in a straight line distance. Upon recovery the drifters were less than 2 km apart from each other. Bathymetry is in metres (m) below mean sea surface.

Other current components are believed to perturb the basic seasonal mean circulation pattern (partial gyre) and tidal currents that dominate circulation on Georges Bank (Butman and Beardsley, 1987). Such perturbations include: 1) tidal components that result in daily, biweekly, and monthly modulations of tidal current magnitude (due to interactions with diurnal and other semidiurnal constituents) and basic shape of the semidiurnal variation (due to higher harmonics such as M4); 2) low frequency current fluctuations that exhibit periods ranging from hours to weeks (due to winds, eddies, and other offshore forcing), which are generally strongest in the upper ocean; and 3) high-frequency current fluctuations with periods ranging from seconds to an hour associated with surface waves, internal waves, and turbulence in the wind-driven surface layer or bottom boundary layer.

Temporal and seasonal variations in the currents of Georges Bank influence various particle retention and dispersion/dilution processes, which themselves vary by spatial position, season, and the occurrence of storms and other episodic events. Rates of dispersion of passive particles on the Bank are characterized by 'residence times', which represent the period over which an initial concentration of particles in a given area is reduced by a fixed fraction (usually represented by the e-folding decay time, e^{-1}), due to natural mixing/dispersion processes. As such, the higher the dispersion rate the lower the residence time and vice versa. The same factors are related to the rate at which a small cluster of particles in such an environment naturally disperse (i.e. spread and dilute) about a centroidal position. Robust estimates for the residence time of passive particles on the Bank, or parts of the Bank, have not been determined. Drifter and model studies suggest that the general residence time of passive particles on the Bank range from 20-80 days, with a strong dependence on the horizontal and vertical release position (Flagg et al., 1982; Page et al., 1998). Other important factors determining extended residence times include the Bank's size and tendency of the seasonal mean circulation to move around rather than across the Bank.

According to some model efforts and drifter studies, the longest residence times are expected for passive particles located on the central Bank, in the lower water column, and in the frontal zone in summer when the gyre circulation pattern inside the 70-m isobath tends to be closed (Limeburner and Beardsley, 1996). The shortest residence times are expected for passive particles located on the Bank's edges, in near surface waters in the winter, and over the outer southern edge of the Bank in summer (Werner et al., 1993; Hannah et al., 1998). Other modeling studies, however, have indicated that there can be important deviations from this pattern, such as the convergence of surface drifters on the central Bank during wind events (Hannah et al., 1998; Drinkwater and Loder, 2001). On the Northeast Peak of Georges Bank, available data indicate that the weakest drift (and hence greatest residence time) occurs at depth on the shallow plateau in winter and spring, when the seasonal mean circulation across the plateau is weak (Loder et al., 1998; Page et al., 1998).

Dispersion/dilution rates of particles and organisms on the Bank depend on buoyancy and active mobility (e.g. swimming), local vertical mixing rates, and local horizontal dispersion rates (including the effects of convergence zones). Strong currents and associated horizontal shears are expected to contribute to relatively high rates of horizontal dispersion for neutrally-buoyant material distributed throughout the water column via mechanisms such as shear dispersion and chaotic stirring (Csanady and Magnell, 1987; Ridderinkhof and Loder, 1994). The Bank's high vertical mixing rates generally contribute to high dilution rates for neutrally buoyant particles, but they would be less effective at diluting positively buoyant particles (e.g. surface oil) or negatively buoyant particles (e.g. drilling cuttings).

Mounting evidence of frequent and widespread near-surface convergence zones on the Bank (i.e. in the frontal zone, at the Bank edge, and in the mixed central area) suggests that, for buoyant materials, the general tendency for high dispersion is often at least partially offset by the concentrating effect of horizontal convergences (Loder et al., 1993; Limeburner and Beardsley, 1996; Drinkwater and Loder, 2001; Lough and Manning, 2001). Similarly, estimates of near-surface horizontal dispersion rates on a scale of 20 km observed on the Bank in summer and fall are often smaller than those observed in other continental shelf environments (Drinkwater and Loder, 2001). These suggest that, occasionally, northeastern Georges Bank exhibits below-normal horizontal dilution rates for buoyant materials despite its strong currents (Drinkwater and Loder, 2001). In addition, the presence of active bedforms observed on the seabed over parts of the Bank can be interpreted as evidence of transient, near-bottom convergence mechanisms that affect dense, negatively buoyant materials.

While much is understood about the general physical regime of Georges Bank, the range of confounding processes and the complexity of their temporal and spatial scales make it difficult to obtain robust quantitative measurements of variables that may influence the fate of materials introduced to the Bank (e.g. marine spills). Many advances, however, have been made in observational and modeling capabilities as a result of intensive studies conducted by the U.S. Global Ocean Ecosystem Dynamics (GLOBEC) Program on Georges Bank from 1994-2000. Results of these studies have been extensively published over the past decade in journals such as Deep-Sea Research II (2001) and the Journal of Geophysical Research (2003).

As part of the GLOBEC program, three intensive studies were carried out regarding physical processes on Georges Bank: 1) water structure and the onset of seasonal stratification – undertaken in 1995; 2) sources, retention, and losses of water and organisms on the Bank – undertaken in 1997; and 3) cross-frontal exchange through the tidal mixing front and shelf/slope front around the eastern and southern edges of the Bank – undertaken in 1999. Many of the important processes addressed by GLOBEC are depicted schematically in Figure 2-8. The following paragraphs provide a summary of some of the physical oceanographic advances that were gained from the GLOBEC program:

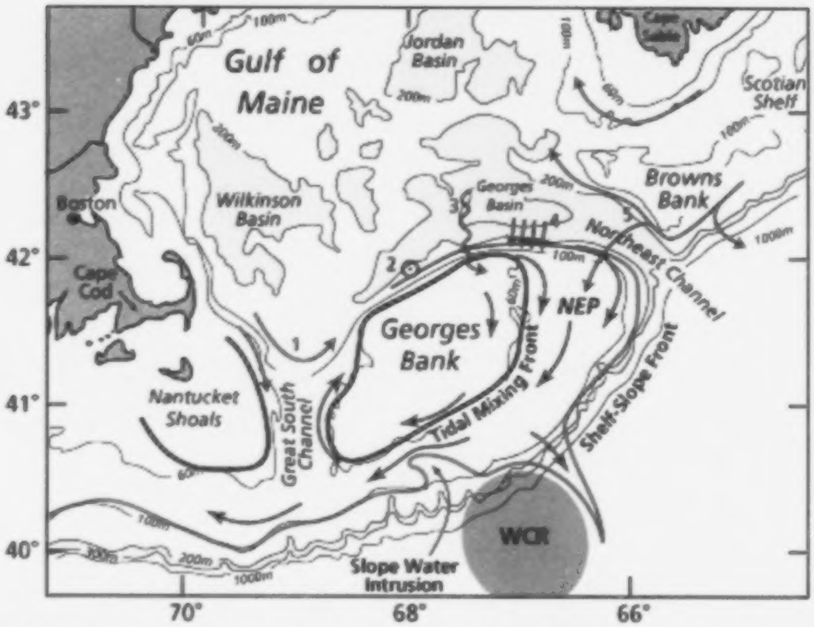

Gulf of Maine
Jordan Basin
Cape Sable
Scotian Shelf
Wilkinson Basin
Boston
Cape Cod
Georges Basin
Browns Bank
Northeast Channel
Georges Bank
NEP
Tidal Mixing Front
Shelf-Slope Front
Nantucket Shoals
Great South Channel
Slope Water Intrusion
WCR
1
2
3
4
5
60m
100m
200m
1000m
43°
42°
41°
40°
70°
68°
66°

Figure 2-8. Georges Bank and Gulf of Maine currents at depths less than 75 m, as depicted during the warm, stratified season (represented by the light blue and red arrows). The tidal mixing fronts around Georges Bank and Nantucket Shoals are indicated by dark blue solid lines. The shelf-slope front along the southern edge of Georges Bank is represented by the orange solid line. Northeast Peak is abbreviated using 'NEP' and Warm Core Ring using 'WCR'. The WCR is shown in green off the southern edge of the Bank. The numbers in red font represent different pathways that water can get onto the northern edge of Georges Bank to start the clockwise circulation around the Bank. These are: 1) flow across the Great South Channel and eastward along the northern edge (the historical view); 2) up onto the Bank in a tidally-driven, near-bottom residual flow; 3) wind-driven, near-surface flow onto the Bank; (4 small-scale, cross-frontal processes; and 5) surface-intensified advection of water from the eastern side of the Northeast Channel, known as 'Scotian Shelf Crossovers.'

Near-surface drift patterns and residence time estimates: Brink et al. (2003) examined the tracks of 203 drifters deployed on the Georges Bank that were drogued at 10 m water depth (following the work of Limeburner and Beardsley, 1996, and Naimie et al., 2001). During all seasons, they observed a clockwise flow around the Bank, with typical residence times increasing from 40 days in winter to 90 days in summer. This pattern suggested a dynamic role in the circulation pattern resulting from summer stratification, in addition to topographic rectification of the tidal currents. Apart from the gyre, primary drivers of the near-surface circulation included strong winter/spring storms and the entrainment of WCRs south of the Bank. Although difficult to discern, all of these features are evident in Figure 2-9a, which depicts all of the near-surface drift tracks (at 10 m depth) collected from Georges Bank and surrounding waters during the GLOBEC program. In particular, note the nearly circular paths offshelf induced by WCRs, the 'leaky' elliptical gyre feeding drifters west onto the New England Shelf, and the insertion of drifters into the gyre from Browns Bank via the 'Scotian Shelf Crossover' mechanism (Figure 2-9b). Paths forming the gyre are predominantly from summer deployments (Brink et al., 2003).

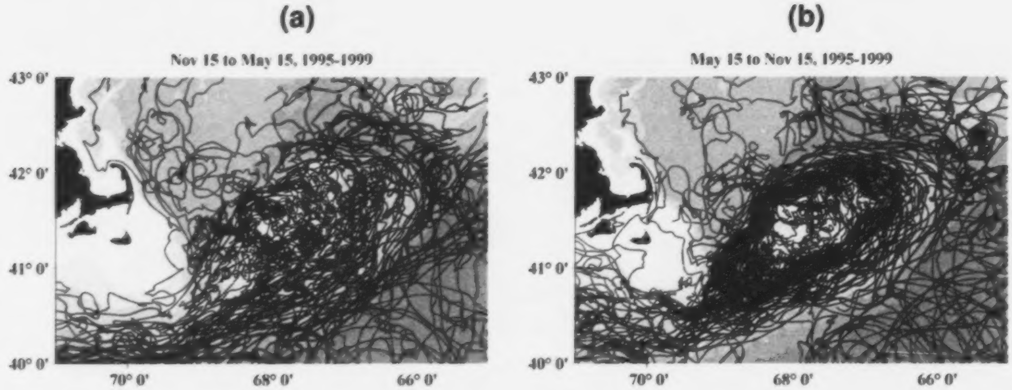


Figure 2-9. Near-surface drifter tracks collected on and around Georges Bank during the GLOBEC program from 1990-1999. Panel (a) outlines winter drifter tracks and panel, (b) summer drifter tracks (images compliments of R. Limburner of Woods Hole Oceanographic Institute, Woods Hole, Massachussetts).

Effect of slope water intrusions onto Georges Bank: Based on salinity profile data from moored instruments and hydrographic surveys, Churchill et al. (2003) classified slope water intrusions as near-surface, near-bottom, or pycnocline. Each intrusion had highly-irregular horizontal structure due to wind forcing and instabilities along the front of the intruding water. Isolated cyclonic features with slope water cores suggest instability of the front of the intrusion, which appeared to be enhanced by the presence of WCRs.

Scotian Shelf Crossovers to Georges Bank: Despite the dynamical constraints of geostrophy related to the steep topography of the Northeast Channel and the retentive gyres on both Georges Bank and Browns Banks, historical data indicates that significant quantities of Scotian Shelf Water occasionally cross the Northeast Channel onto Georges Bank during the winter and spring in surface waters, above 40-60 m water depth. Bisagni and Smith (1998) demonstrated that there is significant interannual variability in the Scotian Shelf Crossover phenomenon and suggested that offshore mesoscale eddies in Northeast Channel may play an important role in triggering such events.

In the winter and spring of 1999, using a combination of moored instruments, drogued drifters, and satellite imagery, Smith et al. (2003) indicated that 20% of the drifters deployed on Browns Bank crossed the 100 m isobath of Georges Bank, exhibiting transit times ranging from 2-26 days. The maximum depth of the crossover surface water ranged from 15-50 m and the residence time of the Scotian Shelf Crossover water on Georges Bank ranged from 3-4 weeks. Primary drivers of the crossover events appeared to be mesoscale features in the Northeast Channel, with minor influences from surface winds (Smith et al., 2003). Frequent crossover events occurred in 1999, which was a year when the Gulf Stream and shelf/slope water fronts were located to the north of there normal positions.

Wishner et al. (2003) attempted to use a biological signature to identify Scotian Shelf Crossover water on Georges Bank. They found no unique assemblages of planktonic indicator species, but they did demonstrate distinct differences in abundance and life history parameters. Population development of the target zooplankton species *Calanus finmarchicus* was found to lag that of the indigenous Georges Bank organisms, yet crossovers were thought to be the dominant source of young *Calanus finmarchicus* in early spring. Also, Dale et al. (2003) found that the internal tide on the northern edge of Georges Bank was modulated by the presence of Scotian Shelf water derived from episodic Scotian Shelf Crossovers. The lighter Scotian Shelf waters are observed to modify the tidal response by inducing mixing from internal waves, which in turn disrupt the normal spring time circulation on the Bank.

Cross-frontal exchange and mixing: Field observations indicate that buoyancy fluxes across the tidal front on the northern edge of Georges Bank are driven primarily by tidal pumping, rather than mean circulation or non-tidal eddy components (Ullman et al., 2003). The tidal flux is directed off-bank near the Bank edge and is associated with a horizontal skew flux of buoyancy along isopycnals, which is divergent at the Bank edge and convergent north of the Bank (Middleton and Loder, 1989). This phenomenon results in upwelling of dense deep water near the bottom at the Bank edge. Model studies have also contributed to our understanding of cross-frontal mixing.

Chen et al. (2003a) used a primitive equation model to identify two distinct pathways for water and associated particle movement on-bank (e.g. zooplankton): 1) over the northern edge an on-bank component of the Lagrangian residual current results in cross-frontal transport near the bottom; and 2) on the southern edge near-bottom convergence toward both the tidal mixing and shelf-slope fronts results in a divergence of near-bottom flow. Moreover, strong winter winds can drive significant off-bank transport that results in a 'washout' of Bank waters. Wind fluctuations coupled with tidal mixing plays an essential role in transporting water and particle (e.g. zooplankton) from stratified to mixed regions in early summer, when thermal stratification is in onset (Chen et al., 2003b). These processes can have important impacts on the cross-frontal flux of copepods and other zooplankton species in the region.

Interannual and decadal variability: Following the work of Petrie and Drinkwater (1993), Loder et al. (2003) demonstrated that monthly anomalies in deep water (i.e. 100-200 m water depth) temperatures on the continental slope can account for 50% of the variance of deep shelf temperatures 3-6 months later. Hydrographic sections observed during cold years in the 1950s and 1960s indicated that the anomalous conditions arose from episodic extensions of Labrador Slope Water (LSW) along the shelf break (extending from the tail of the Grand Bank to Georges Bank and beyond) followed by shelf intrusions. The extensions appear to be associated with long-term variability in the atmospheric pressure patterns over the North Atlantic, as indexed by the North Atlantic Oscillation (NAO). The NAO is due to a difference in sea-level pressure between Iceland and the Azores. In fact, sustained lows in the NAO index appear to be highly-correlated with increased transport of the LSW around the tail of Georges Bank, followed by cold, fresh intrusions into deep shelf water regions that lag by 1-2 years. The lag is due to advection timescales.

An example of such an event was described by Drinkwater et al. (1998), whereby an extreme NAO minimum in the winter of 1996-1997 was related to increased LSW transport that reached the mouth of the Northeast Channel more than two years later, in January, 1998. Figure 2-10 indicates the progressive arrival times of LSW on the Scotian Shelf and Gulf of Maine during this period. Figure 2-11 outlines LSW 'flushing' through the Gulf of Maine over a one year period. Hydrographic data from the Northeast Channel in 1999 indicates that the LSW source had been replaced by the more conventional Warm Slope Water (WSW); origin is a subtropical gyre. Changes in the relative contribution of water to Georges Bank from various sources (i.e. LSW, WSW, etc.) affect the temperature and salinity (among other properties) of the water mass (Friedland and Hare, 2007). These changes can impact processes such as nutrient cycling (Ji et al., 2008), as well as have subsequent ecological consequences such as changes to growth and reproduction of organisms.

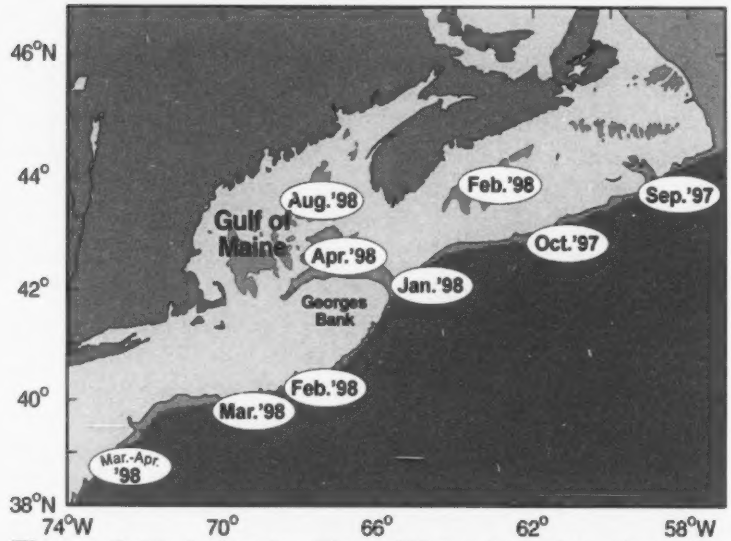

46°N
44°
42°
40°
38°N
74°W
70°
66°
62°
58°W
Gulf of Maine
Aug.'98
Apr.'98
Georges Bank
Jan.'98
Feb.'98
Sep.'97
Oct.'97
Feb.'98
Mar.'98
Mar.-Apr. '98

Figure 2-10. Labrador Slope Water intrusion along the shelf break and into the deep basins following the 1996-1997 North Atlantic Oscillation event.

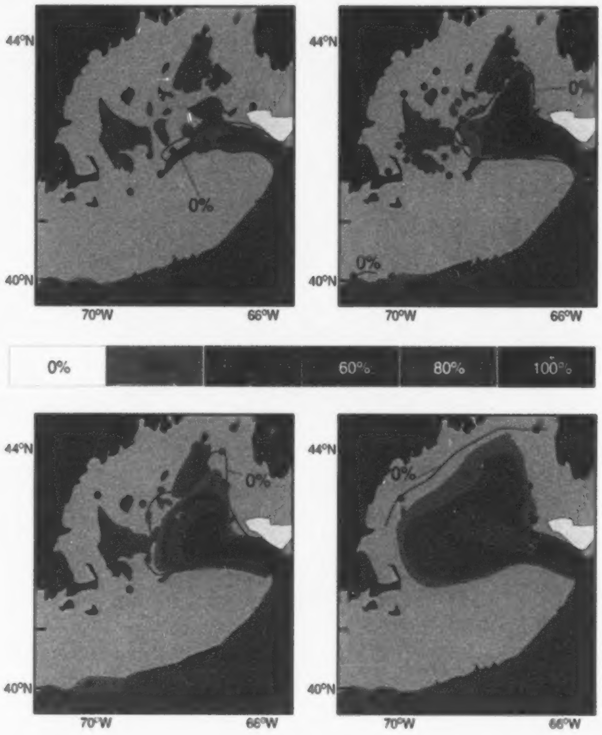

44°N
40°N
70°W
66°W
0%
0%
60%
80%
100%

Figure 2-11. Penetration of Labrador Slope Water (LSW) into the Gulf of Maine from January to August, 1998. Colours represent the percentage of LSW observed below 100 m water depth.

2.3 GEOLOGY

The subsurface underlying Georges Bank can be divided into four geological provinces, based on thousands of kilometres of multichannel seismic data (Figure 2-12). First, Long Island Platform is characterized by a seaward dipping wedge of sediments and sedimentary rock, overlying a crystalline basement complex that extends from the Fall Line to about the 3 km isopach with little or no hydrocarbon potential. Second, Georges Bank Basin is a south-southwest plunging structural low beneath western Georges Bank, which developed as a sag in a relatively stable platform. Much of its early sedimentation was dominated by carbonate facies, attesting to its stability and lack of significant sources of clastic sediments. Subsequent sandstone and shale facies show little variation or structure. The basin was the site of exploratory drilling in the early 1980s, with no reported occurrences of hydrocarbons. However, with a sedimentary thickness of 10 km or so and, an associated carbonate front, some potential may exist beneath the continental slope. Third, Yarmouth Arch is a south tilted basement high lying to the east of Georges Bank Basin, with little hydrocarbon potential.

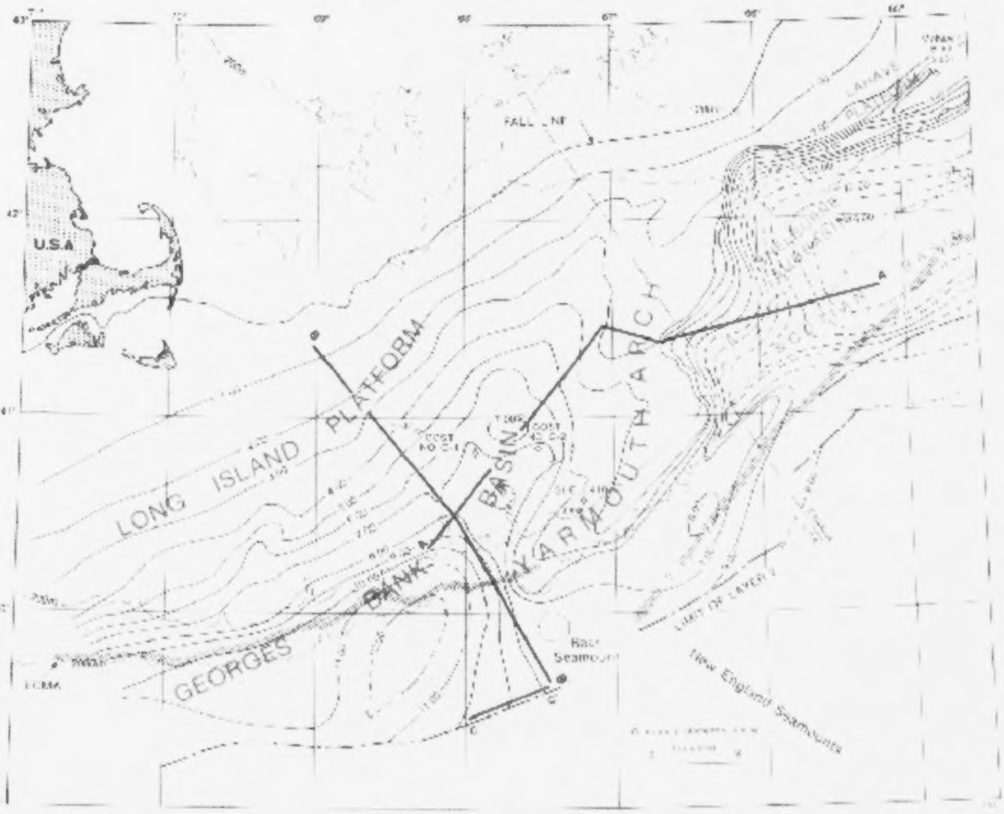


Figure 2-12. Depth to the breakup unconformity and major tectonic elements, Georges Bank Basin. The shaded area is the positive axis of the East Coast Magnetic Anomaly.

Last, Shelburne Subbasin is located beneath eastern Georges Bank, Northwest Channel, and the southwest corner of the Scotian Shelf. It lies almost entirely to the east of the Canada/U.S. maritime boundary. It is the western most subbasin of the Scotian Basin, which extends northeast to the western Grand Banks. In contrast to Georges Bank Basin, Shelburne Subbasin experienced more rapid subsidence and is interpreted to contain thick deltaic sandstone facies inter-tonguing with marine shales; the source of which was a river system that drained the ancestral Gulf of Maine, Bay of Fundy, and adjacent upland areas. These deltaic beds, together with deeper water prodelta facies, overlie a thick, mobile salt unit that has resulted in the development of large down-to-the-basin fault systems and numerous diapiric salt structures (Figures 2-13 and 2-14). The prominent carbonate front, which occurs beneath much of the Scotian Shelf, is not well developed in Shelburne Subbasin due to the influx of large volumes of deltaic sediments. Significant hydrocarbon potential has been assigned to this undrilled subbasin by a number of exploration companies, as well as in resource assessments conducted by Natural Resources Canada in the 1980s. Play types, similar to those in the Sable Island area of the Scotian Shelf, are expected to occur in the Shelburne Subbasin.

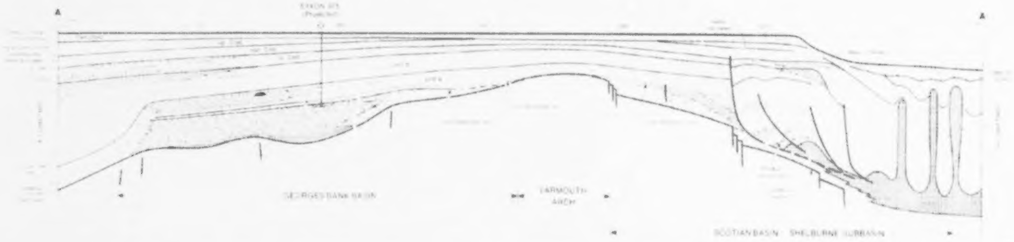


Figure 2-13. Geological cross-section A-A' (refer to Figure 2-12) from Georges Bank Basin to the Scotian Basin showing stratigraphical relationships.

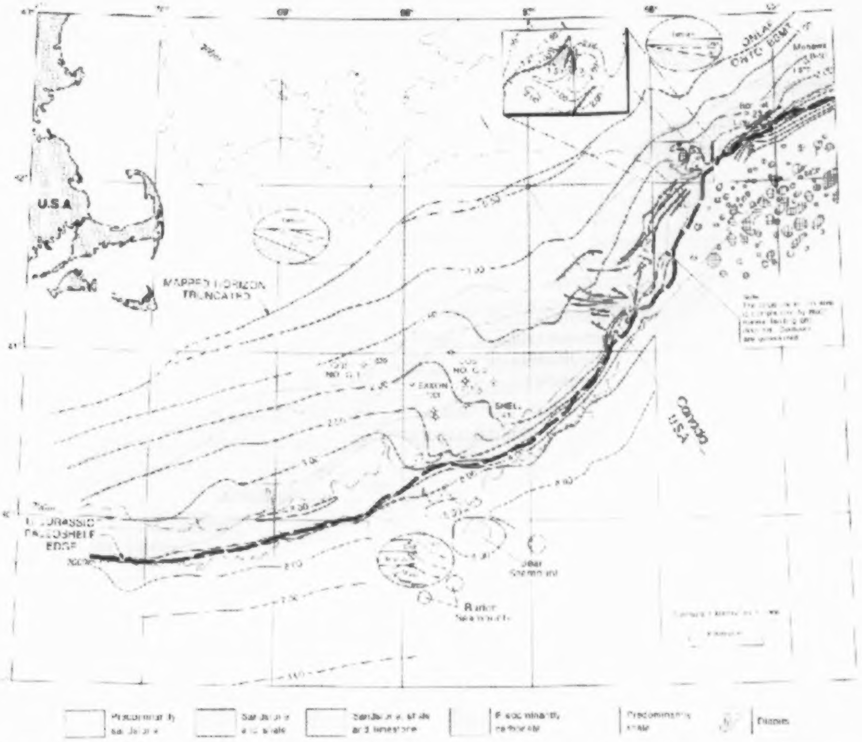

U.S.A
MAPPED HORIZON TRUNCATED
UPPER JURASSIC PALEOSHELF EDGE
EXXON
SHELL
Canada
USA
Bear Seamount
Predominantly sandstone
Sandstone and shale
Sandstone, shale and limestone
Predominantly carbonate
Predominantly shale
Diapirs

Figure 2-14. Contours on the top of the Jurassic with generalized unit b (Upper Jurassic) facies of sequence 2.

2.4 SEDIMENTOLOGY

The surficial sediments on top of Canada's portion of Georges Bank consist of large expanses of sand substrate, interspersed with gravel and mixed sediment regions (Figure 2-15). Unique bottom features on Georges Bank include a permanent gravel pavement occupying the Northeast Peak. Sand waves and ripples occur over sandy areas, with the largest (up to 14 m in height) found in the northwest region of the Bank. In contrast, the relative abundance of fine sediment increases with water depth, particularly below 60-100 m depth where turbulence from tidal currents and wind-waves is less pronounced. Fine sediment is most prevalent along the southern edge of the Bank, where reduced winnowing and sediment deposition likely occurs (Boudreau et al., 1999).

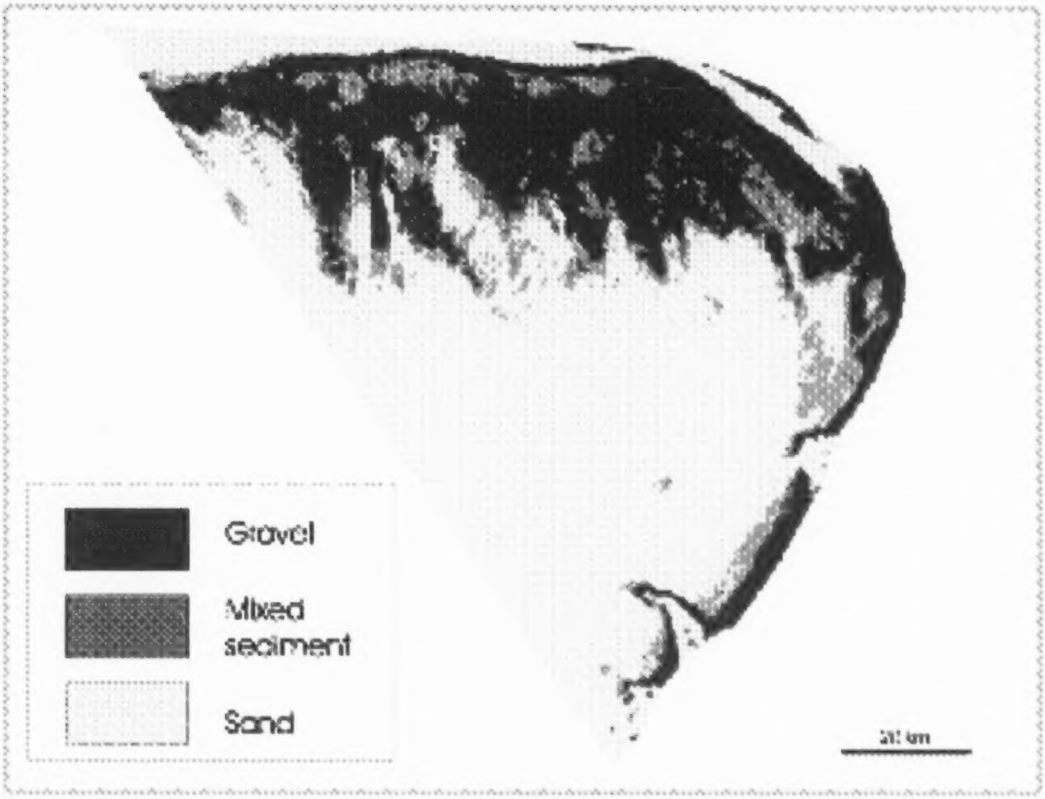


Figure 2-15. Bottom sediment grain-size on Canada's portion of Georges Bank. Data was obtained by way of multibeam, grab sample analysis, and bottom video collected from Natural Resources Canada and the U.S. Geological Service. Sand is represented by grain sizes ranging from 0.0063-2 millimetres (mm) in diameter. Gravel is all material greater than 2mm in diameter (Kostylev et al., 2005).

Canyons on the southern edge also export fine sediment to deeper waters, where sandy muds are found. Large glacial erratics and boulders, which increase structural complexity, can be found interspersed with the gravel. The grain size of bottom sediment is generally determined by the balance between shear stress at the bottom and the supply of sediment. On continental shelves, where sediment supply is limited, the bottom sediment grain size is primarily a function of wave height (George and Hill, 2008). On Georges Bank, however, tidal currents and Pleistocene geology also play significant roles (Shepard et al., 1934; Kostolev et al., 2005; Uchupi and Bolmer, 2008). As a result, bottom sediments on the central plateau of Georges Bank, where water depth is the shallowest and shear stress is greatest, are primarily composed of coarse sediments such as sand and gravel (Figure 2-15).

On Georges Bank, frictional velocities associated with strong tidal currents and waves can rework surficial sediments on the seabed, particularly during winter storm events, leading to near bottom suspended sediment concentrations on the order of 0.5-1 grams per litre (g L^{-1}) (Backus and Bourne, 1987; Muschenheim and Milligan, 1998) (Figure 2-16). Factors that influence the near bottom suspended sediment concentrations include erosion and resuspension of bottom sediments and the settling and deposition of suspended sediment; a significant proportion of which is organic material (Muschenheim and Milligan, 1998).

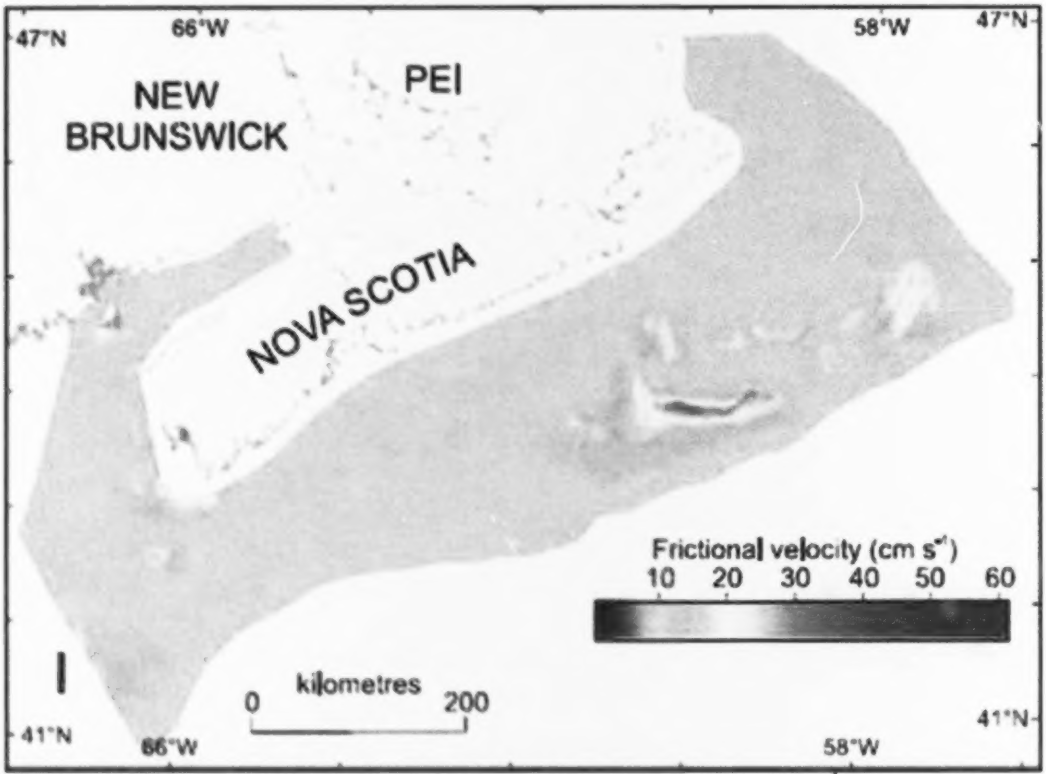


Figure 2-16. Frictional velocities (centimeters per second, cm s^{-1}) in the offshore of Nova Scotia produced from tidal currents (Kostylev and Hannah, 2007).

In the near bed region, termed the 'benthic boundary layer', the vertical distribution of both particle size and concentration is a function of current shear and settling velocity of the particles. The result is a benthic boundary layer where large, fast sinking particles are found near the bottom and smaller, slow sinking particles are found upwards in the flow. The equilibrium profile of this material in suspension varies with shear stress generated by tidal currents and waves. The fact that slower sinking particles are found in areas where flow speed is higher leads to dispersion of the material. Observations demonstrate that both tidal and seasonal mean currents contribute to elevated rates of suspended sediment dispersion on Georges Bank, although the magnitude varies by location across the Bank.

Increased magnitude and spatial complexity of sediment drift and dispersion rates can be expected at times when there are strong perturbations to the basic tidal and seasonal mean flows due to other flow components such as storms and internal waves. On the Northeast Peak of Georges Bank, dispersion rates of coarse sediments (i.e. sediments moving along or just above the seabed) increase towards the centre of the Bank, where tidal currents are strongest and are the primary source of vertical shear in the near-bottom region. In contrast, the largest dispersion rates for fine grained sediment, which is suspended farther up in the water column, occurs along the northern edge of the Bank. This is due to the seasonal mean current that is the primary contributor to vertical shear at mid water depths. The depositional areas of fine grain sediment from the Bank are the Mud Patch located south of Cape Cod, Gulf of Maine, canyons along the southern edge of the Bank, and the adjacent continental slope.

The location and distribution of benthic organisms and fish on the Bank are closely linked to both sediment texture and the quality of seston (i.e. the organic material being deposited on the bottom). High rates of primary productivity found on Georges Bank and in the Bay of Fundy lead to elevated fluxes of carbon that can enhance benthic production. The combination of these factors leads to biological community relationships, including the biogenic sand-gravel and sand-shell fauna assemblages on the Bank (Thouzeau et al., 1991), presence of various coral communities associated with the coarse gravel substrates of the Northeast Channel (Mortensen et al., 2006), and the very productive scallop fishery. The gravel pavement on the Northeast Peak, which covers an underlying sandy seabed, is important for the attachment of juvenile sea scallops, nursery ground for juvenile cod and haddock, and is a habitat that provides an important food source for demersal fish (Lough et al., 1989; Collie et al., 2009).

Methratta and Link (2006) presented mean biomass of seven species generally associated with fine-grained sediments (e.g. goosefish, white hake, red hake, silver hake, witch flounder, American plaice, and thorny skate) in six substrate types in the Gulf of Maine-Georges Bank region (Figure 2-17). They demonstrated that these species tended to concentrate in fine sand, silt, and clay environments. They also demonstrated mean biomass of seven species generally associated with coarse-grained sediments (e.g. Atlantic cod, haddock, winter flounder, longhorn sculpin, sea raven, and winter skate) in six substrate types in the Gulf of Maine-Georges Bank region (Figure 2-18). Results demonstrated that these species tended to concentrate in coarse rock, fine rock, and coarse sand environments.

The substrate on Georges Bank is susceptible to a range of natural and anthropogenic activities such as storms, fishing, and oil and gas activities. For example, side scan sonar images have demonstrated disturbance to the gravel pavement by mobile fishing gear (Valentine and Lough, 1991). If sediment armoring was changed by either removing or disturbing the gravel-sized bed sediment, the sand below could be subject to erosion and transport that may blanket the surrounding gravel, resulting in changes to the local substrate composition.

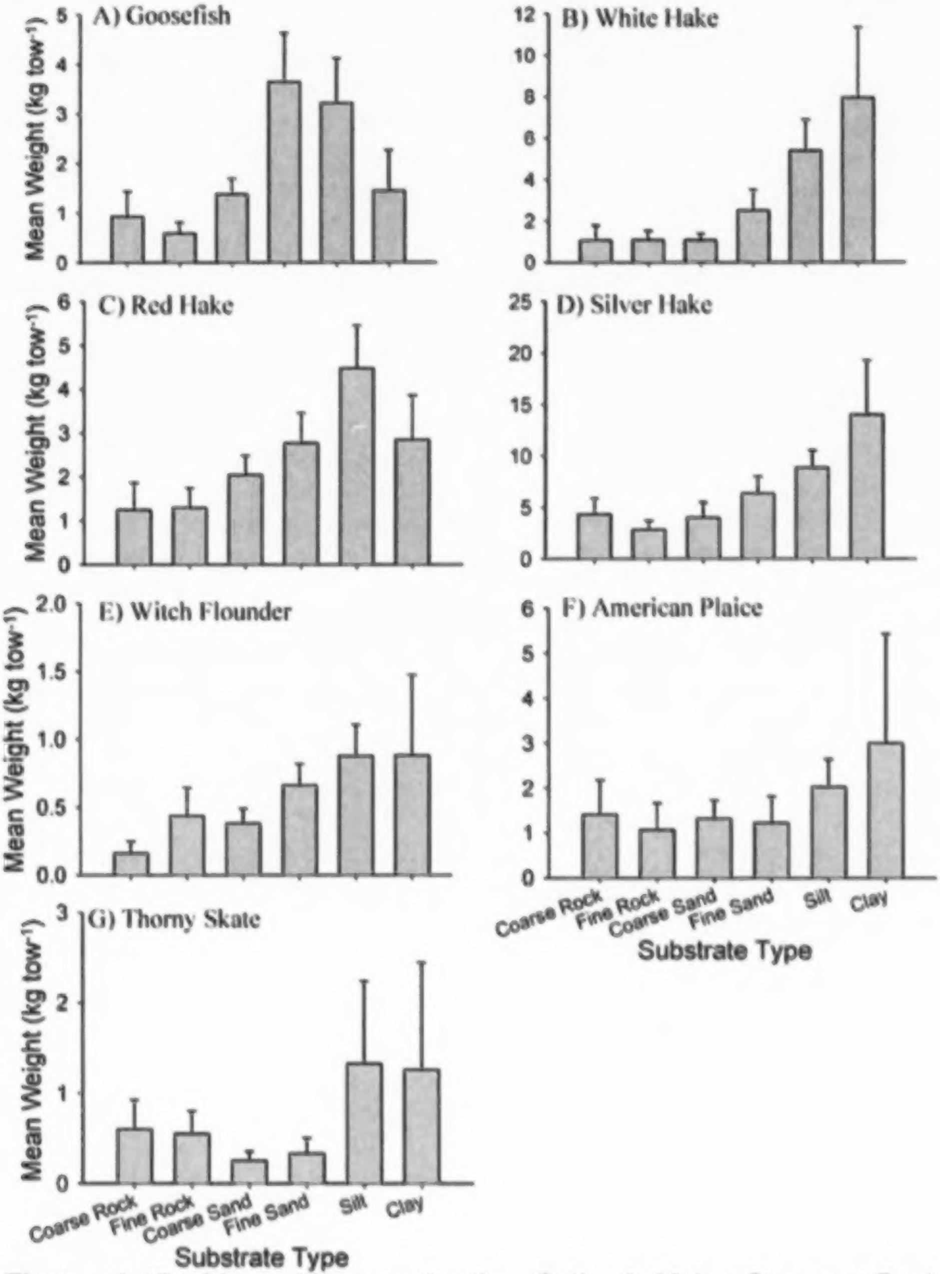


Figure 2-17. Mean biomass in the Gulf of Maine-Georges Bank region (kilograms per tow, kg tow^{-1}) for select marine species by substrate type. The species generally prefer fine-grained sediments as a substrate type. The bars represent the 95% confidence interval about the mean value (Methratta and Link, 2006).

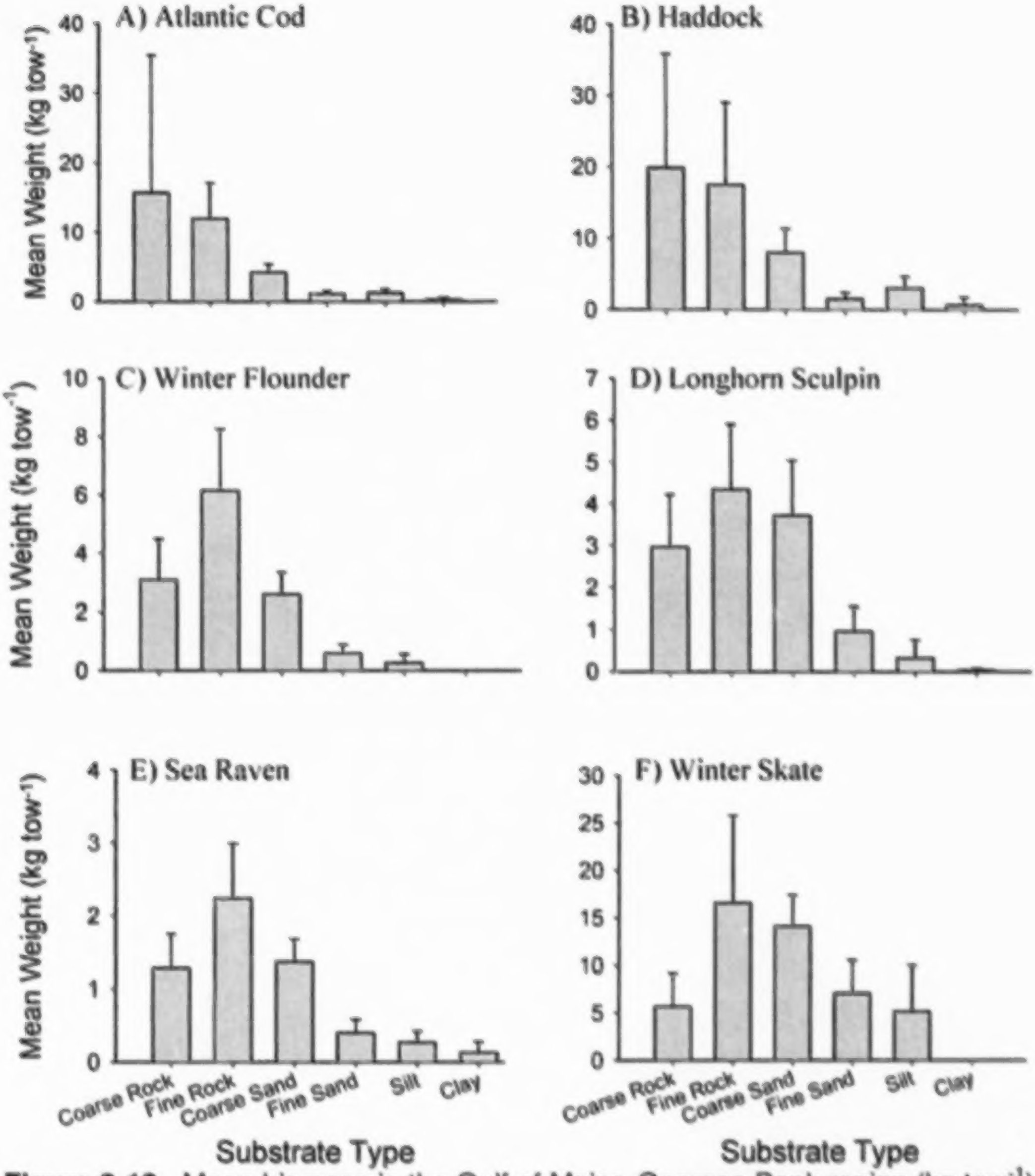


Figure 2-18. Mean biomass in the Gulf of Maine-Georges Bank region (kg tow^{-1}) for select marine species by substrate type. The species generally prefer coarse-grained sediments as a substrate type. The bars represent the 95% confidence interval about the mean value (Methratta and Link, 2006).

2.5 TROPHIC INTERACTIONS

The Georges Bank moratorium area consists of a highly productive ecosystem. Phytoplankton and fisheries production is higher than in the neighbouring Gulf of Maine, Scotian Shelf, and North Sea (Cohen and Grosslein, 1987). Growth rates of both haddock and scallop on Georges Bank are greater than those of other northwest stocks of these species (Schuck and Arnold, 1951; Black et al., 1993). The physical attributes characterizing this area, which have been described in previous sections, contribute to its high productivity (Backus and Bourne, 1987; Boudreau et al., 1999; Franks and Chen, 2001; Wiebe et al., 2002). The fronts and gyre around Georges Bank facilitates the upwelling of nutrients on to the Bank and into the photic zone, enhancing plankton production, which propagates up the food web through to the rich shellfish and finfish populations that occupy the Bank. At 61-63 tonnes per squared kilometre (t km^{-2}), lower trophic level biomass in the Gulf of Maine and Georges Bank is estimated to be composed of 50% zooplankton, 40% primary producers (e.g. phytoplankton), and 10% bacteria (Gaichas et al., 2009).

The high primary productivity on Georges Bank supports an abundance and diversity of marine species that spend some or all of their life histories on Georges Bank. For most fish species, the spawning period is a sensitive time when the growth of eggs and larvae are susceptible to natural and human-made perturbations in the surrounding environment. Perturbations that affect the timing and rate of primary production and subsequent zooplankton production can affect the recruitment success of commercially-important species. A delay in the spring bloom by a few weeks, for example, can influence recruitment of larval fish and shellfish into the population (Cushing, 1990). Table 2-1 outlines the timing of various life stages for select invertebrates and commercial fish species that occupy Georges Bank.

Table 2-1. Timing of various life stages for select invertebrates and commercial fish species that occupy Georges Bank (modified from Boudreau et al., 1999).

		Month											
Species	Life Stage	J	F	M	A	M	J	J	A	S	O	N	D
Scallop	larvae					←	→		←	—	→		
Lobster	larvae						←	→					
Cod	spawning		←	→									
	larvae			←	—	→							
Haddock	spawning			←	→								
	larvae			←	—	→							
Yellowtail	spawning			←	—	—	—	—	→				
	larvae				←	—	—	→					
Herring	adults			←	—	—	—	—	—	—	—	→	
	spawning									←	—	→	
	larvae	←	—	→							←	—	→

Species of the Georges Bank ecosystem are linked through a web of trophic interactions (i.e. feeding). The Georges Bank ecosystem encompasses five trophic levels that range from primary producers and grazers to upper level predators such as sharks (Link et al., 2008), including detritus and other feedback loops. Nutrients are plentiful on Georges Bank because of offshore upwelling along the shelf-slope break and movements of slope water into the Gulf of Maine through the Northeast channel (Townsend et al., 2006). This makes Georges Bank a very productive area.

Energy is transferred through the ecosystem via trophic interactions. Georges Bank is a highly-connected ecosystem (Link, 2002), as indicated by several factors such as the spatial and temporal openness of the marine ecosystem, omnivorous and generalist feeding habits, moderate dietary overlap between species, and size-based (ontogenic) diet shifts. There is a trend toward increased piscivory with size in many species on the Bank (e.g. Atlantic cod). The dietary overlap between species is frequently higher than the overlap between size classes of the same species, as predators may vary their focus among prey depending on availability (Garrison and Link, 2000a).

There are two main energy pathways on Georges Bank: pelagic and benthic. Phytoplankton is at the base of the marine food-web and the primary source of nutrition for zooplankton. Phytoplankton and zooplankton are food for larval fish and invertebrates, as well as higher level predators such as leatherback turtles, seabirds, and North Atlantic right whales. At the base of benthic pathway is detritus, which is organic waste that is generated by species that reside throughout the water column. Detritus eventually descends to the benthos. Benthic species, such as clams and other mollusks, filter phytoplankton and suspended detritus from the water column, while other groups depend on the organic content of sediments or detritus that has reached the seafloor for their energetic needs (e.g. certain species of marine worms).

Atlantic herring are a key forage species on Georges Bank and are critical to the transfer of energy from lower trophic levels to higher trophic levels (Link et al., 2008). Other mid-trophic species include small pelagics, small demersal fish, and crustacean species such as crab and shrimp. Mid-trophic levels have an important role in the transfer of energy in marine systems (i.e. benthic and pelagic pathways) and are important prey items for fish and larger crustaceans (Link et al., 2008; NEFSC, 2009). The diet of adult cod and haddock, for example, consists of fish, crustaceans, and molluscs. The diet of halibut includes shrimp, crab, and fish, such as sand lance (Cargnelli et al., 1999; Lough, 2004; Brodzick, 2005). It has also been suggested that trophic linkages from primary production to fish include benthic populations, with suspension feeders considered a critical pathway for transfers to higher trophic levels (Boudreau et al., 1999).

Transfer to the highest trophic levels is often through pelagic pathways. The diets of porbeagle and thresher sharks, for example, consist primarily of pelagic fish. Squid, shellfish, and crustaceans are also consumed. Although fish are the dominant prey of sharks, some sharks are also planktonic consumers. For instance, basking sharks are very large slow-moving planktonic feeders with a diet that primarily consists of copepods, other zooplankton, fish eggs, and larvae. These are both examples of pelagic energy pathways between the lower trophic level and top level predators. The number and variety of connections between trophic levels demonstrates the complexity of the Georges Bank marine ecosystem and highlights some of the challenges in understanding the relationships between species that occupy the region. Although there are numerous interactions, few are of the magnitude to drive whole system dynamics. Due to the dietary overlap, omnivorous, and generalist nature of species and ontogenic diet shifts of predators, it is unlikely that one species is directly impacted by populations of other species (Garrison and Link, 2000b; Link, 2002).

2.6 PLANKTON

2.6.1 Bacterioplankton

Bacterioplankton are prokaryotes (i.e. *Bacteria* and *Archaea*) that constitute the smallest free-living cells in any pelagic ecosystem. In the Gulf of Maine-Georges Bank region, as elsewhere in the ocean, some bacterioplankton use light as a sole or major energy source (i.e. photoautotrophs), others use light as an auxiliary energy source (i.e. photoheterotrophs), while the majority of bacterioplankton use organic material as an energy source (i.e. heterotrophs). Approximately 2% of bacterioplankton on Georges Bank are photoautotrophs (i.e. cyanobacteria), which contribute directly to primary production. Early studies to identify heterotrophic bacteria relied on laboratory isolation on agar plates, although it is known that this method recovers no more than about 1% of the total community.

On Georges Bank, abundant isolates are *Pseudomonas* and *Aeromonas* (Hobbie et al., 1987). Less abundant isolates are *Flavobacterium, Micrococcus, Planococcus, Bacillus, Enterobacter, Vibrio, Photobacterium, Alcaligenes,* and *Lucibacterium* (Hobbie et al., 1987). The vast majority of microbial diversity is resistant to culture, but can be typed by phylogeny according to gene sequences. Bacteria in the Gulf of Maine comprise the dominant SAR11 phylotype cluster (*Pelagibacter*), while other highly-abundant phylotypes are the SAR86-like cluster, SAR116-like cluster, *Roseobacter, Rhodospirillaceae, Acidomicrobidae, Flavobacteriales, Cytophaga*, and unclassified *Alphaproteobacteria* and *Gammaproteobacteria* clusters (Li et al., 2009a). It is estimated that there are 1.6×10^{25} prokaryotic cells throughout the water column in the entire Gulf of Maine Area, of which 1.9×10^{24} may be found on Georges Bank (Li et al., 2009a). Assuming a carbon content of 10 femtograms (fg) per cell and carbon dry weight of 50%, the biomass of bacterioplankton in the waters of Georges Bank is estimated to be 37,000 tonnes (t) dry weight. The rate of bacterial production is estimated to be 20 milligrams-of-Carbon per cubic metre per day (mgC m^{-3} d^{-1}) (Hobbie et al., 1987). This is equivalent to approximately one turnover of the biomass per day.

Although the spatial distribution of bacterioplankton has not been systematically mapped on Georges Bank, a linkage to phytoplankton chlorophyll at different scales is evident from some studies. For example, for a transect across Georges Bank along its minor axis during spring, there was coherent variation of the microbial groups from transect station to station (Hobbie et al., 1987). Furthermore, at a given station, chlorophyll and bacterioplankton can exhibit parallel vertical distributions from the sea surface to the bottom of the photic zone (Figure 2-19). The trophic linkage between phytoplankton (i.e. primary producers) and bacterioplankton (i.e. secondary producers) is mediated through the flux of dissolved organic material derived from phytoplankton exudation, cell autolysis, viral lysis, and egesta released from grazers that have consumed phytoplankton. Although cell-to-cell interactions between microbes occur at small scales of time and space, the ecological linkage is evidently propagated to multiyear changes in regional ocean areas (Li et al., 2006). As such, with further research, it may be possible to deduce the spatial distribution of various microbial groups on the basis of phytoplankton chlorophyll mapped by remote sensing in conjunction with local ecological considerations.

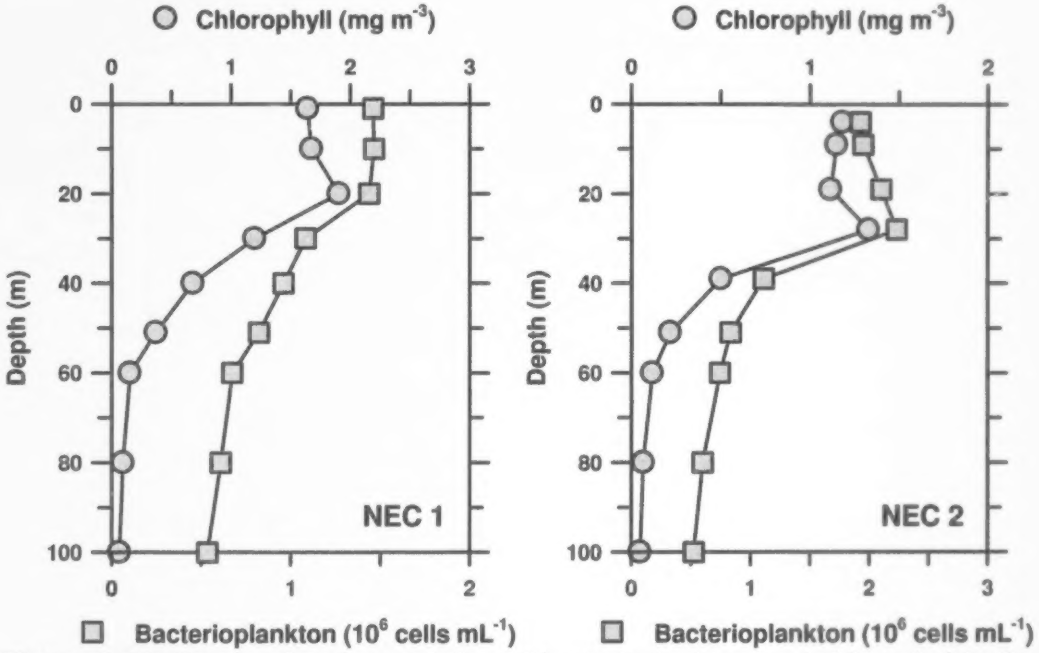


Figure 2-19. Depth-related covariation of bacterioplankton and chlorophyll in the upper 100 m of the water column at 2 hydrographic stations in the Northeast Channel (NEC) of the Georges Bank moratorium area in June 2005 (Li et al., 2009a).

2.6.2 Phytoplankton

Phytoplankton includes bacteria, unicellular algae, and protists that perform oxygen-evolving photosynthesis. Despite tremendous phylogenetic diversity, all phytoplankton share the common feature of possessing chlorophyll *a* (or its divinyl derivative) as the primary light-harvesting pigment. As such, from an operational standpoint, the quantity of phytoplankton in the sea is most often measured as the concentration of chlorophyll *a*. The cytoplasm of some planktonic ciliates contains either modified algal endosymbionts or isolated plastids. This chimaeric microzooplankton performs photosynthesis, some in an obligate fashion comparable to algae and others in a facultative fashion as mixotrophs (i.e. capable of mixed modes of nutrition). There is great interest in the abundance and distribution of phytoplankton, as they play a vital role in aquatic ecosystem dynamics. Phytoplankton is the base of the marine food web and the primary source of nutrition for the animal component of plankton known as zooplankton (DFO, 2009a).

Townsend et al. (2006) is the most authoritative review of phytoplankton dynamics on Georges Bank. It describes the annual cycle of new and recycled production as an outcome of surface circulation, upwelling nutrient injections, tidal-pumping from nutrient-rich deep slope water, and microbial nitrification. Average annual phytoplankton production levels on Georges Bank are estimated to be 379 gC m^{-2} y^{-1} or 4270 t km^{-2} (Cohen and Grosslein, 1987; Gaichas et al., 2009). The yearly production cycle is highly variable, with the highest phytoplankton concentrations occurring during late winter or early spring, with lower concentrations occurring during summer. Seasonal differences in primary production are mainly related to variations in nutrient supply (e.g. nitrate, phosphate, and silicate) and light. On Georges Bank, planktonic ciliates that photosynthesize can contribute from 1-7% of the total fixed carbon. In the size class of microplankton, to which they belong, the ciliates can contribute from 14-90% of the fixed carbon (Stoecker et al., 1989).

High phytoplankton concentrations are observed following the formation of the seasonal thermal stratification during the winter-spring transition period, at a time when nutrient concentrations are high throughout the water column. Strong winter mixing and tidal influences contribute to the upwelling of deep, nutrient rich water, while seasonal heating of surface waters results in the development of strong upper stratification around the Bank. The nutrients and heat provide ideal growing conditions for phytoplankton, and a bloom will typically occur. The bloom ends once nutrients are depleted in surface waters, but may be further shortened by weather events, self-shading, and zooplankton grazing pressure (Breeze et al., 2002; Ji et al., 2008). Primary production is lowest in the stratified deeper water surrounding Georges Bank, especially in the summer, as nutrients become exhausted and are not replenished. These patterns are reflected in data collected from Georges Bank in the 1980s, as part of the Marine Resources Monitoring, Assessment, and Prediction Program (MARMAP). The data provided detailed spatial and temporal distributions of phytoplankton biomass and productivity (O'Reilly and Busch, 1984; O'Reilly et al., 1987). A secondary, less pronounced bloom is evident during de-stratification of the water column in the fall (i.e. typically October).

The phytoplankton community of Georges Bank is dominated by diatoms during the spring, late autumn, and winter and flagellates increase in importance during the summer and post-bloom (DFO, 2006a). Recent coupled ecosystem-circulation models have confirmed earlier field observations (e.g. Horne et al., 1989; Bisagni, 2003) that both local (i.e. biological) and external (i.e. physical) processes determine the seasonal nutrient supply and primary productivity of Georges Bank (Hu et al., 2008; Ji et al., 2008). In summer, internal nitrogen regeneration is the major nitrogen source for primary production on the central Bank, while mixing processes (e.g. tidal pumping and advection) fuel production on the flanks and bank-wide during other seasons. These models have also suggested that changes in the deep source waters, modulated by remote forcing (e.g. NAO and changes in Arctic outflow), influence nutrient fluxes to the Bank and its productivity.

Chlorophyll concentration generally ranges from 1-5 mg m^{-3} on Georges Bank, with the annual maximum typically occurring in late March (Page et al., 2001; Thomas et al., 2003; Frank et al., 2006). Satellite (SeaWiFS) measurements of chlorophyll *a* concentration are available at 4 km spatial resolution and 1 week time resolution throughout the Gulf of Maine over an 11 year period (1997-2007). The data suggests there is no significant multiyear trend (Figure 2-20). A physiographic partition of this large area into 14 distinct regions has allowed an analysis of phytoplankton climatology and multiyear change on Georges Bank to be assessed in relation to neighbouring waters (Wolff and Incze, 2009).

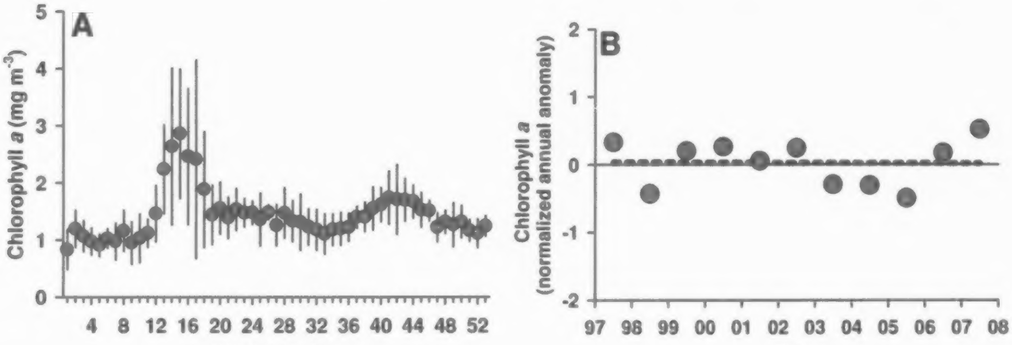


Figure 2-20. Georges Bank phytoplankton: (A) annual cycle showing mean and standard deviation of weekly chlorophyll a concentration (mg m^{-3}) from 11 years of SeaWiFS observations; and (B) time series of normalized annual cholorphyll a anomaly indicating no significant multiyear trend (Li et al., 2009a).

Annual cycles of chlorophyll *a* show different amplitudes and timings across the 14 regions, although spring and fall phytoplankton blooms are common features almost everywhere. One exception is the Bay of Fundy, where high concentrations of suspended non-phytoplankton material may contaminate the presumed signal from chlorophyll *a*. In a ranked sequence of annual maximum chlorophyll, Georges Bank occupies a middle position between high concentrations of coastal shelf regions and low concentrations of shelf Basins (i.e. Georges, Wilkinson, Jordan) and the central Gulf of Maine (Figure 2-21A). The principal source of nutrients to the Gulf of Maine is the deep, nutrient-rich continental slope waters.

Steele at al. (2007) have suggested that the source of these deep, nutrient-rich waters has played a significant role in the overall productivity of Georges Bank, from plankton to fish, over the past several decades. In recent years, for example, there has been a greater contribution of colder and fresher deep waters originating upstream (i.e. Scotian Shelf and off-shelf LSW) linked to Arctic ice melt. As a result, there is now a lower residual concentration of nitrate (i.e. nitrate minus silicate) in the Gulf of Maine that may alter biomass, productivity, and community composition of phytoplankton (Townsend et al., 2009). An analysis of multiyear chlorophyll change in the 14 physiographic regions of the Gulf of Maine indicates that phytoplankton appear to be increasing in the shallow coastal shelf regions but decreasing over deep waters. Georges Bank is a region pivoted between positive and negative change (Figure 2-21B).

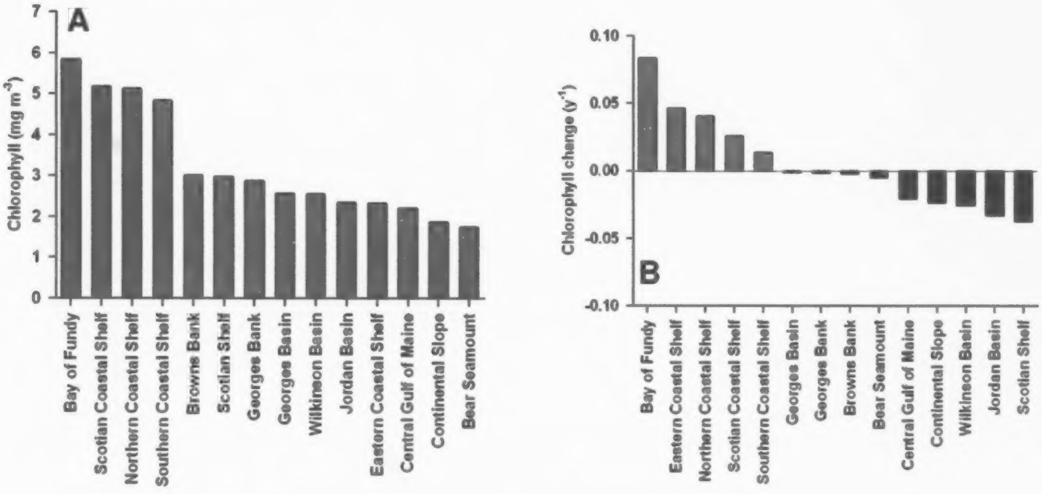


Figure 2-21. Gulf of Maine Area phytoplankton physiographic regions: (A) maximum annual chlorophyll concentration (mg m^{-3}) per region; and (B) multiyear rate of chlorophyll change (y^{-1}) calculated from the linear regression of normalized annual anomaly time series data (Li et al., 2009a).

2.6.3 Zooplankton

Zooplankton includes animals that are unable to maintain their horizontal spatial distribution against current flow. Zooplankton range in size from 20 micrometres (µm) to more than 2 m in diameter. One commonly used size classification scheme divides zooplankton into: microzooplankton (20-200 µm), which includes ciliates, tintinnids, and the eggs and larvae of larger taxa; mesozooplankton (200 µm-20 mm), which include copepods, larvaceans, pelagic molluscs (pteropods and heteropods), and larvae of benthic organisms; macrozooplankton (2-20 centimetres, cm), which include krill (euphausiids), arrow worms (chaetognaths), and amphipods; and megazooplankton (20 cm-2 m), which include larger, gelatinous taxa (Sieburth et al., 1978). Many zooplankton species consume phytoplankton and repackage the energy fixed by primary producers in larger-sized particles that can be consumed by higher trophic level organisms, such as fish, seabirds, and marine mammals.

Zooplankton have a diverse range of life history characteristics that mediate their response to environmental variability and influence their spatial distribution, seasonal timing, and interannual variability. For example, different groups may consume phytoplankton, zooplankton, detritus, or some combination; they have different physiological tolerances to environmental variables such as temperature and salinity, as well as may have different 'refuge' traits such as dormancy or vertical migration. Different gear types are required to quantitatively sample zooplankton of different sizes, and zooplankton sampling efforts on Georges Bank have been dominated by gear equipped with mesh sizes that capture mesozooplankton most efficiently. For this reason, variability patterns are better characterized for this group than for the smaller and larger size classes that may occupy the Bank.

The mesozooplankton community on Georges Bank is dominated by relatively few species. Six copepod species make up approximately 80% of the abundance of the mesozooplankton community at any given time of year (Davis, 1987). These species include: *Calanus finmarchicus* and *Pseudocalanus* sp. (winter/spring dominants); *Paracalanus parvus*, *Centropages typicus,* and *Centropages hamatus* (summer/ fall dominants); and *Oithona similis* (abundant year-round) (Davis, 1987). Twenty three taxa constitute approximately 95% of the total mesozooplankton abundance on Georges Bank (Kane, 2007). The Georges Bank zooplankton community has a strong seasonal cycle in terms of both abundance and biomass. Total zooplankton abundance is highest in May-June, reaching average concentrations on the order of 10^3 individuals m^{-3} (Kane, 2007). Zooplankton displacement volume, a proxy for biomass, is also highest in May-June and lowest in December-January for all regions of the Bank (Sherman et al., 1987). While displacement volumes follow the same seasonal cycle in all sub-regions of the Bank, they are lower on the flanks of the Bank compared to within the 100 m depth contour.

Calanus finmarchicus is the biomass dominant zooplankton species on the Bank and in much of the Gulf of Maine. Its life cycle includes a period of dormancy (i.e. suppressed development) in the late summer and fall in deep water, such as Gulf of Maine basins. Prior to dormancy, the species builds up a large oil sac containing storage lipids, fulfilling a role in the ecosystem as a large, energy rich species that is an important food source for planktivorous fish such as herring and for Northern right whales. Larvae of *C. finmarchicus* are prey for larval cod and herring on the Northeast Peak of Georges Bank, as are the larvae of another abundant copepod *Pseudocalanus* sp. (Buckley and Durbin, 2006). The Gulf of Maine is the primary source of *C. finmarchicus* to the Bank in late winter, when they emerge from dormancy, migrate to surface waters, and are transported onto the northern Flank and Northeast Peak of the Bank (Bigelow, 1926; Lynch et al., 1998).

As the *C. finmarchicus* population increases on the Bank from January to April, the impact of the gyre circulation on population development is evident. The Bank is in high abundance of younger stages (nauplii) on the Northeast Peak proximal to where mature adults arrived on the Bank and spawned, as well as in high abundance of older stages (copepodids) downstream of the Northeast Peak on the Southern Flank where they were transported as they grew and developed (Durbin and Casas, 2006). A similar interaction between circulation and population development has been observed in *Pseudocalanus* spp. on Georges Bank (Davis, 1984). Although phytoplankton production on Georges Bank is high throughout the year, food limitation on growth and reproduction has been observed in *C. finmarchicus* on the Southern Flank in April to May in certain years (Wiebe et al., 2002).

The abundance of invertebrate predators of zooplankton, including chaetognaths, suspended hydroids, medusae, euphausiids, and amphipods, is highest on the crest of the Bank (Sullivan and Meise, 1996). For *C. finmarchicus*, off-bank advection results in the greatest losses from the Bank in January, while predation on eggs by older-stage *C. finmarchicus* and planktonic hydroids is the dominant source of mortality in the late winter and spring (Ohman et al., 2008). Although a substantial portion of the zooplankton produced on the Bank is transported off the bank, particularly toward the southwest onto Nantucket Shoal and toward the Mid-Atlantic Bight, modeling studies have demonstrated that taxa developing in the Georges Bank gyre can be retained on the Bank. For example, some of the *C. finmarchicus* that develop on the Bank are retained in the gyre and could contribute to their source region in the western Gulf of Maine (Miller et al., 1998). In addition, a portion of the sea scallop larvae spawned on Georges Bank scallop beds are retained on the Bank and can re-seed either their source bed or other Georges Bank scallop beds (Gilbert et al., 2010).

In contrast to species like *C. finmarchicus*, *Pseudocalanus* spp., and *Metridia* spp., which have off-bank sources and are abundant in the stratified regions of the Bank, several species including *Centropages typicus*, *Centropages hamatus*, and *Temora longicornis* have on-bank sources and their populations are centered on the retentive crest of Georges Bank, as well as in the tidal mixing front (Durbin and Casas, 2006). These species are most abundant in the summer and fall. In addition, zooplankton can be transported onto Georges Bank from intrusions of WSW and WCRs that bring warm-water oceanic zooplankton species onto the Bank (Colton et al., 1962; Brown et al., 2005). Inputs of Scotian Shelf Water crossing the Northeast Channel onto the Northeast Peak can transport cold-water shelf species, similar to the Bank community, onto Georges Bank (Wishner et al., 2003).

Zooplankton biomass on Georges Bank can vary considerably from year to year, based on observations since 1971 (Wiebe et al., 2002). Winter, early spring, and spring zooplankton biomass on Georges Bank have been at intermediate levels during the past several years. There is some evidence that zooplankton abundance has been increasing in the winter (January-February), but decreasing in the spring (March-April) (NOAA, 2008). Mean zooplankton biomass on the Bank in February 2009 was the highest concentration observed in DFO surveys since 1999 at 70 g m^{-3} (average of approximately 20 g m^{-3}) (Harrison et al., 2009). The abundance of *C. finmarchicus* also varies from year to year, and the interannual variability patterns of this species are similar in the Gulf of Maine and on Georges Bank (Figure 2-22).

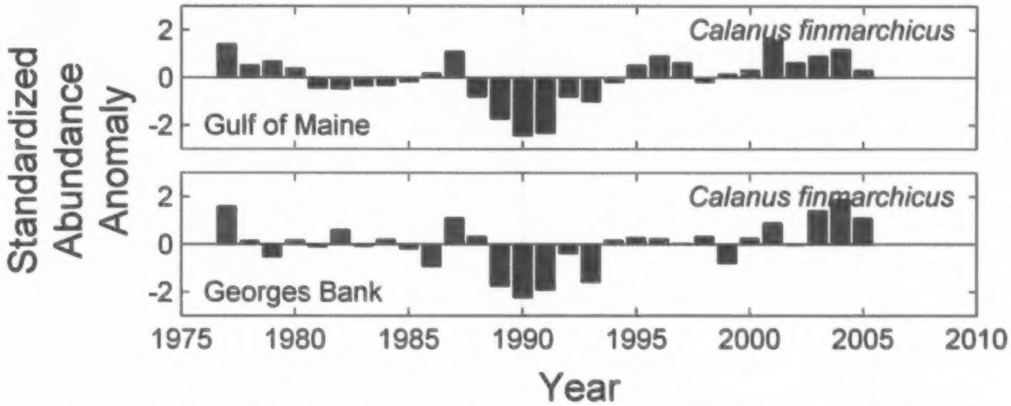


Figure 2-22. Mean annual abundance of Calanus finmarchicus in the Gulf of Maine and on Georges Bank, based on NEFSC plankton monitoring sampling using bongo gear (pers comm. M. Fogarty – NEFSC National Oceanic and Atmospheric Administration, 2009).

On Georges Bank, *C. finmarchicus* abundance was lower than average from 1989-1993. After a period of approximately average abundance in the mid-1990s to early-2000s, *C. finmarchicus* abundance increased sharply in 2003, reaching a time-series maximum in 2004 (Kane, 2007). Abundance anomalies (i.e. annual average abundance with the seasonal abundance cycle removed) of *C. finmarchicus*, a cold-water, winter-spring dominant species, were negatively correlated with temperature in the time series, while abundance anomalies of

Centropages typicus and *Centropages hamatus*, warm-water, summer-fall species, were positively correlated with temperature (Kane, 2007). The abundance trends of several species of copepods on Georges Bank are correlated with one another from year to year. The abundance of *Centropages typicus*, *Metridia lucens*, *Temora longicornis*, and *Oithona* spp. all increased to above average or average values from 1989-2001 (Figure 2-23) (Kane, 2007). The abundance of *C. typicus*, *M. lucens*, and *T. longicornis* declined beginning in 2002, while the abundance of *Oithona* sp. continued to be abundant (Kane, 2007). Similar coherent interannual variability patterns have also been observed among small copepod species in the Gulf of Maine (Pershing et al., 2005; Greene and Pershing, 2007).

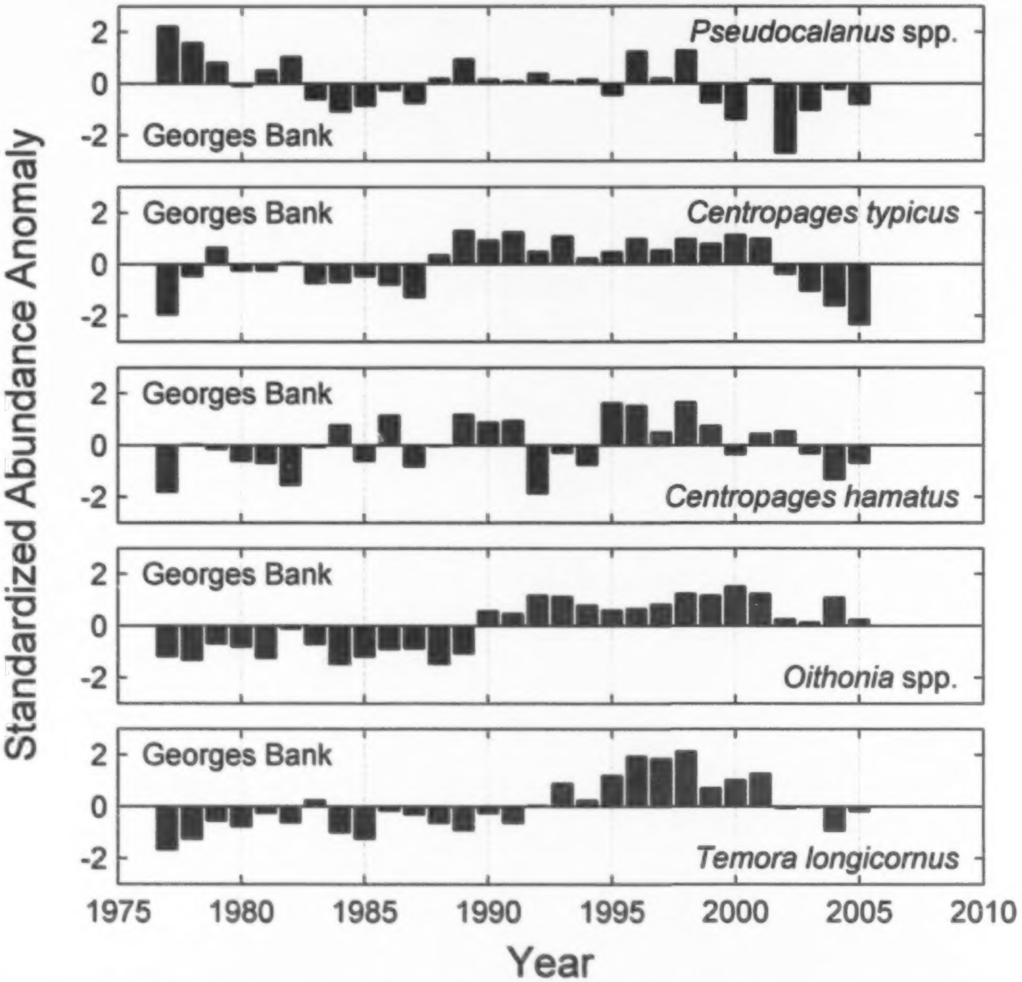


Figure 2-23. Mean annual abundance of Pseudocalanus sp., Centropages typicus, C. hamatus, Oithona spp., and Temora longicornis in the Gulf of Maine and on Georges Bank, based on NEFSC plankton monitoring sampling using bongo gear (pers comm. M. Fogarty – NEFSC National Oceanic and Atmospheric Administration, 2009).

The Georges Bank zooplankton community shift of the 1990s coincided with a decrease in salinity in the Gulf of Maine and on Georges Bank caused by increased inflow from the Scotian Shelf (Kane, 2007). Survival of these species through autumn may be enhanced when low salinity waters move into the eastern Gulf of Maine from the Scotian Shelf and stabilize the water column. This would allow phytoplankton to grow during the autumn or winter when the water column is normally well mixed (Durbin et al., 2003; Pershing et al., 2005; Kane, 2007). This hypothesis is supported by observation of much higher abundances of *C. typicus*, *Oithona* sp., *Pseudocalanus* sp., *M. lucen*, and late-stage *C. finmarchicus* in the central Gulf of Maine in the winter of 1999, which was a year when colder, lower-salinity water was present in the Gulf of Maine and a winter bloom occurred. This is in contrast to the winter of 2000, when conditions were more typical, exhibiting higher surface salinity, no winter bloom, and low copepod abundance (Durbin et al., 2003).

Alternatively, advective input could also have contributed to changes in the zooplankton community in the 1990s (Kane, 2007). The species that increased in abundance in the 1990s have diverse life histories and phenologies and occupy a range of ecological niches (Pershing et al., 2005). As such, zooplankton community shifts, such as those observed on Georges Bank in the past several decades, are likely to influence the pathways, magnitude, and seasonal timing of energy transfer throughout the Georges Bank ecosystem.

2.7 BENTHIC INVERTEBRATES

A number of studies have attempted to document and describe the benthic fauna, including worms, clams, sea stars, sea urchins, crustceans, sea cucumbers, tunicates, sponges, hydroids, and corals of Georges Bank, often in relation to sediment type and some description of seasonal trends (Wigley, 1961; Maurer and Leathem, 1980; Dickinson and Wigley, 1981; Maurer and Leathem, 1981a,b; Maurer, 1983; Michael et al., 1983; Maciolek and Grassle, 1987; Theroux and Grosslein, 1987). A study by Cohen and Grosslein (1987) estimated that the production of macrobenthos on Georges Bank was similar to the Gulf of Maine and slightly higher than the Scotian Shelf. An analysis of data collected from the mouth of the Bay of Fundy to southwestern New England in the 1950s and 1960s indicated high densities of 1961 specimens per squared-metre and biomass of 233 g m^{-2} of macrobenthos on Georges Bank (similar to the southern New England Shelf and higher than the Gulf of Maine), but lower densities of 300 specimens per squared-metre and 21 g m^{-2} on Georges Slope (similar to the southern New England slope) (Theroux and Wigley, 1998).

In a study of benthic organisms retained in a 10 mm mesh sieve on the Northeast Peak of Georges Bank, 140 taxa were identified with 76% of which were epibenthic (Thouzeau et al., 1991). The epibenthic species collected included: polychaetes (23%), gastropods (19%), crustaceans (14%), echinoderms (12%), poriferans (7%), acidians (7%), and bivalves (7%). Infauna species were mostly bivalves (58%) and polycheates (24%). Bivalves dominated in density (55%) and biomass (86%), with three species (i.e. scallops, surf clams, and ocean quahogs – each with discrete distributions) representing 71% of total biomass. This was noted to reflect the leading role of filter-feeders on the Northeast Peak. Bivalve predators, such as decapods, boring gastropods, and echinoderms, exhibited density dependent relationships with their prey. Overall, densities generally declined with depth, with sediment type considered to be the major factor influencing the distribution of benthic organisms. The highest diversity of organisms was found on biogenic habitat, containing polycheate tube structures. Epibenthic sessile taxa (i.e. sea squirts, sponges, sea anemones and coral) demonstrated low abundance and biomass, though they were regularly observed.

A more recent study by Link (2004) analyzed the U.S. groundfish stomach database from the Gulf of Maine area to determine whether benthic species had declined in the period since the intensive sampling of the 1950s and 1960s, as well as to determine whether groundfish diets might be used to detect changes in benthic communities rather than by direct sampling. The study indicated that most species examined had not declined over the previous 30 years, with two groups (i.e. sea stars and mantis shrimp) exhibiting a slight increase in relative abundance (Link, 2004). More recently, direct investigations of benthic communities (i.e. megafauna greater than 5 mm in size) on Georges Bank have been conducted, in order to investigate the impacts of human disturbance (Collie et al., 1997; Collie et al., 2000; Collie et al., 2004; Link et al., 2004; Collie et al., 2009). The studies indicate that fragile species, such as a tube-building polycheate (*Thelepus cincinnatus*), brittlestar (*Ophiopholis aculeata*), toad crab (*Hyas coarctatus*), and shrimp (*Dichelopandalus leptocerus*), were found in higher abundance at less disturbed sites (Sites 13 and 17 in Figure 2-24). In contrast, bivalves and echinoderms tended to dominate at a more disturbed site (Site 20 in Figure 2-24).

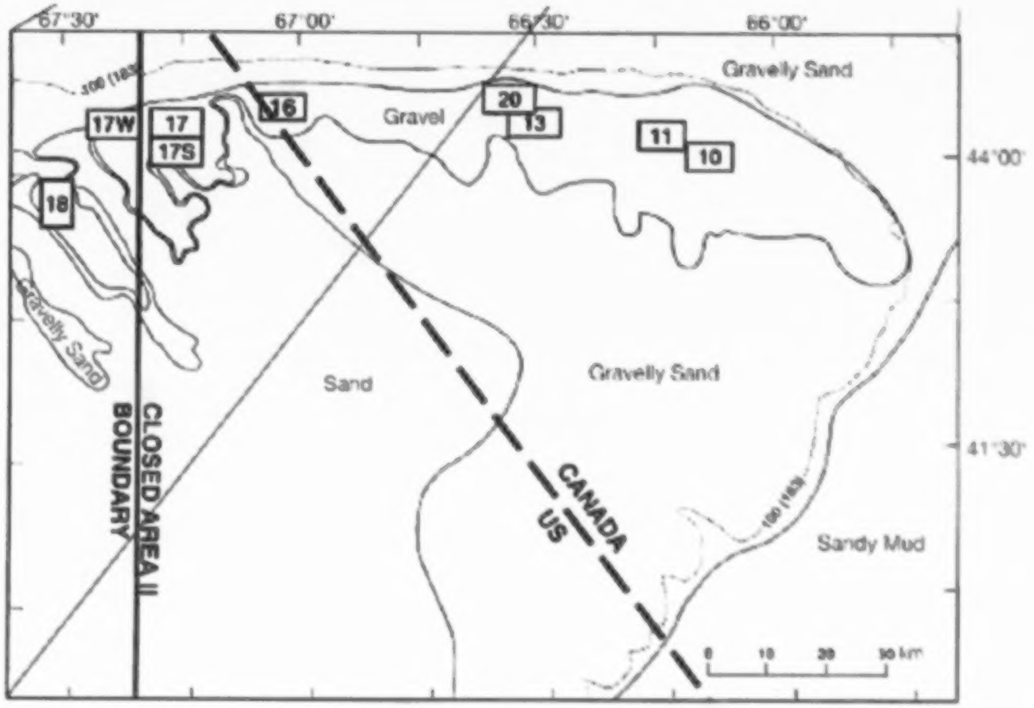

67°30'
67°00'
66°30'
66°00'
44°00'
41°30'
100 (183)
Gravelly Sand
Gravel
17W
17
17S
16
20
13
11
10
18
Gravelly Sand
Sand
Gravelly Sand
CLOSED AREA II BOUNDARY
CANADA
US
100 (183)
Sandy Mud
0 10 20 30 km

Figure 2-24. Benthic locations sampled from 1994-2000.

The studies also demonstrated that changes in community structure occurred after a fishery closure in 1995 at a gravel site (Site 17 in Figure 2-24), which transitioned from bare gravel in 1994, to biogenic cover grazed by nudibraches by 1996, to colonization by sponges, hydrozoans, crabs, and small scallops by 1997 and, last, to increased sponge cover with small colonies of Filograna by 1999. The number of species found at Site 17 increased from 24 in 1994 to 54 in 2000. Biomass and production were also found to increase at the site. Select benthic species are summarized in the Appendix.

2.7.1 Ahermatypic Corals

Distribution, Habitat, Abundance, and Predator and Prey

Ahermatypic corals (hereafter referred to as corals) do not contain zooxanthellae (algae) and, as such, are not restricted to shallow depths where high levels of light penetrate. They can exist, however, at almost any depth from the shallow intertidal zone to the deep abyss. Compared with similar shallow-water corals, ahermatypic corals are poorly studied in part due to their inaccessibility, since most species are found at depths greater than 200 m of the continental slopes, canyons, or seamounts.

Population Structure Relative to Moratorium Area

Since Gordon and Kenchington (2007) reviewed the distribution of corals in the DFO Maritimes Region, data from scientific research missions targeting corals have significantly increased the knowledge of the distribution of the taxa (Cogswell et al., 2009). Thirty-one coral taxa are now known to occur in the Georges Bank moratorium area (Table 2-2). These are primarily Octocorallia (soft corals), although some Hexacorallia (stony corals) have also been identified. Not all of these taxa are mutually exclusive due to difficulties in identification of specimens from photographs alone, although, 17 specimens have been identified down to the species level and another five down to genera level. At least 22 species or coral have been identified in the moratorium area, indicating a diverse coral fauna in the region.

In June 2002, the Northeast Channel Coral Conservation Area (NEC CCA) was established by DFO (Mortensen and Buhl-Mortensen, 2004). The NEC CCA lies inside the Georges Bank moratorium area (Figure 2-25). The conservation area was primarily selected on the basis of its high density of large branching gorgonian corals, such as *Paragorgia arborea* and *Primnoa resedaeformis* compared with the surrounding area (Mortensen and Buhl-Mortensen, 2004) (Figure 2-26). The NEC CCA was also established because of visual evidence of disturbance, such as broken live coral, tilted corals, and skeletal fragments, indicating that the area was vulnerable to bottom fishing damage. The closest, high density aggregations in Canadian waters are found to the east of the Gully Marine Protected Area (MPA). Large gorgonian corals are not found in the Bay of Fundy, in high concentrations on Brown's Bank, or elsewhere on the western Scotian Shelf.

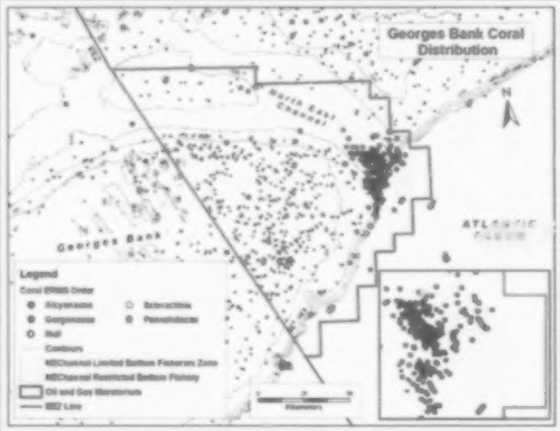


Figure 2-25. Major coral groups of the Georges Bank moratorium area (marked in orange). Boundaries of the Northeast Channel Coral Conservation Area are more clearly defined in the inset (green shaded area). Data on the graphic are from multiple sources (Cogswell et al., 2009).

Table 2-2. Coral taxa found in the Georges Bank moratorium area.

Coral Taxon	Type	Common Name
Anthomastus agassizii	Alcyonacean	Mushroom coral
Anthomastus grandiflorus	Alcyonacean	Mushroom coral
Anthomastus spp.	Alcyonacean	Mushroom coral
Capnella florida	Alcyonacean	Broccoli coral
Nephtheidae	Alcyonacean	Soft coral
Acanella arbuscula	Gorgonian	Maple trees
Acanthogorgia armata	Gorgonian	
Anthothela grandiflora	Gorgonian	
Gorgonacea	Gorgonian	
Keratoisis ornata	Gorgonian	Bamboo coral
Paragorgia arborea	Gorgonian	Bubblegum coral
Paragorgia sp.	Gorgonian	Bubblegum coral
Paramuricea borealis	Gorgonian	
Paramuricea grandis	Gorgonian	
Paramuricea placomus	Gorgonian	
Paramuricea spp.	Gorgonian	
Primnoa resedaeformis	Gorgonian	Sea corn
Primnoa sp.	Gorgonian	Sea corn
Radicipes spp.	Gorgonian	
Anthoptilum murrayi	Pennatulacean	Sea pen
Balticina finmarchica	Pennatulacean	Sea pen
Halipteris spp.	Pennatulacean	Sea pen
Kophobelemnon sp.	Pennatulacean	Sea pen
Pennatula spp.	Pennatulacean	Sea pen
Octocorallia		
Desmophyllum spp.	Scleractinian	
Flabellum angulare	Scleractinian	Cup coral
Flabellum spp.	Scleractinian	Cup coral
Lophelia pertusa	Scleractinian	Spider hazards
Stephanocyathus diadema	Scleractinian	
Anthozoa		

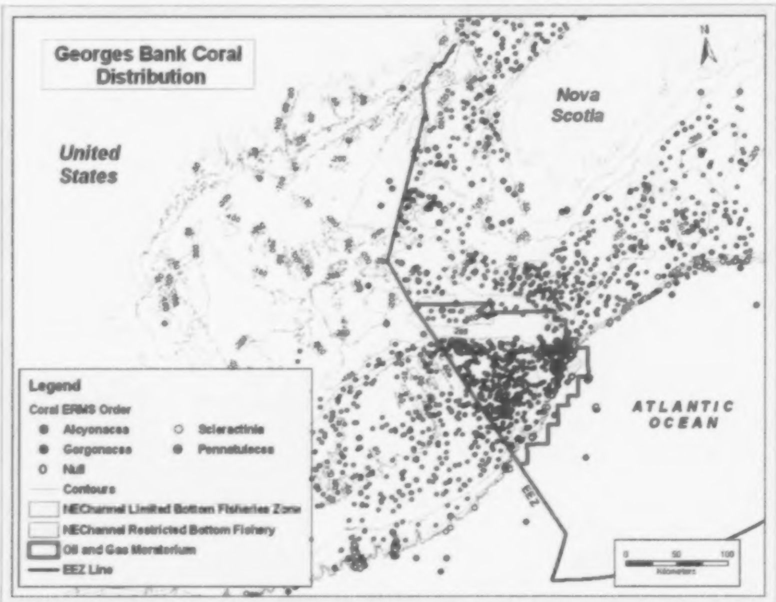

Georges Bank Coral Distribution
United States
Nova Scotia
ATLANTIC OCEAN
N
EEZ
Legend
Coral ERMS Order
● Alcyonacea
○ Scleractinia
● Gorgonacea
● Pennatulacea
○ Null
Contours
NEChannel Limited Bottom Fisheries Zone
NEChannel Restricted Bottom Fishery
Oil and Gas Moratorium
EEZ Line
0
50
100
Kilometers

Figure 2-26. Major coral groups of the Georges Bank moratorium area (marked in orange) and surrounding regions. Data on the graphic are from multiple sources (Cogswell et al., 2009).

Life History, Location, and Timing

Corals form important structural habitats that contribute to vertical relief and increase the availability of microhabitats (Tissot et al., 2006). Coral habitats provide feeding opportunities for aggregating species, hiding places from predators, nursery areas for juveniles, fish spawning aggregation sites, and attachment substrates for fish egg cases and sedentary invertebrates (Fosså et al., 2002; Reed, 2002; Etnoyer and Morgan, 2003). For example, in the Northeast Channel, redfish were almost four times more common in video sequences in the presence of corals than in the absence of corals (Metaxas and Davis, 2005; Mortensen et al., 2006).

Known Vulnerabilities

Most corals are highly vulnerable to human activities, in particular, bottom contacting activities such as fishing. Corals are filter feeders and, as such, are also vulnerable to intake of organic and inorganic contaminants in the water column and in bottom sediments. The various impacts of oil pollution and dispersants are reviewed by Haapkylä et al. (2007).

Status Designation

There is a strong international conservation movement calling for the protection of corals using closed areas and bans on certain fishing gear types. The NEC

CCA is 424 km^2 in area and consists of two fishing management zones (Figure 2-25). A restricted bottom fishing zone comprises approximately 90% of the CCA, which is closed to all bottom fishing gear used for groundfish or invertebrate fisheries (e.g. longline, otter trawl, gillnet, and trap). The remaining 10% of the CCA is open to limited authorized fishing. At present, the limited fishing area is open only to longline fishing gear for groundfish in the presence of an at-sea observer, but remains closed to all other bottom fishing gear.

2.7.2 Sea Scallop

Distribution, Habitat, Abundance, and Predator and Prey

Sea scallop, *Placopecten magellanicus*, occupies a geographic range in the northwest Atlantic Ocean that extends from Labrador to Cape Hatteras, North Carolina. Georges Bank is the largest and most productive scallop area in this range (Brand, 2006). It supports an abundance of sea scallops due to its ideal benthic habitat that results from the water temperature, food and oxygen availability, substrate type, and other oceanographic conditions that contribute to spawning and settlement success. Sea scallops prefer sandy, gravel bottoms on the Bank and occur at shallow water depths of 35-120 m (DFO, 2008a). It is worth noting that dense aggregations of juveniles are often found in areas where the density of adults has been low and, as such, the distribution of juveniles does not necessarily match the distribution of adults at any one time (Figure 2-27).

Sea scallops are filter-feeders and their diet consists mainly of phytoplankton. The growth rate of scallops varies from one area to another and is likely influenced by season, depth, food availability, and water temperature. Georges Bank, as previously described, exhibits unique environmental conditions that result in rapid movement of well mixed water rich in food and oxygen. The Bank is one of the world's most productive areas for the species and represents some of the fastest observed growth rates for sea scallop stocks (Bourne, 1964).

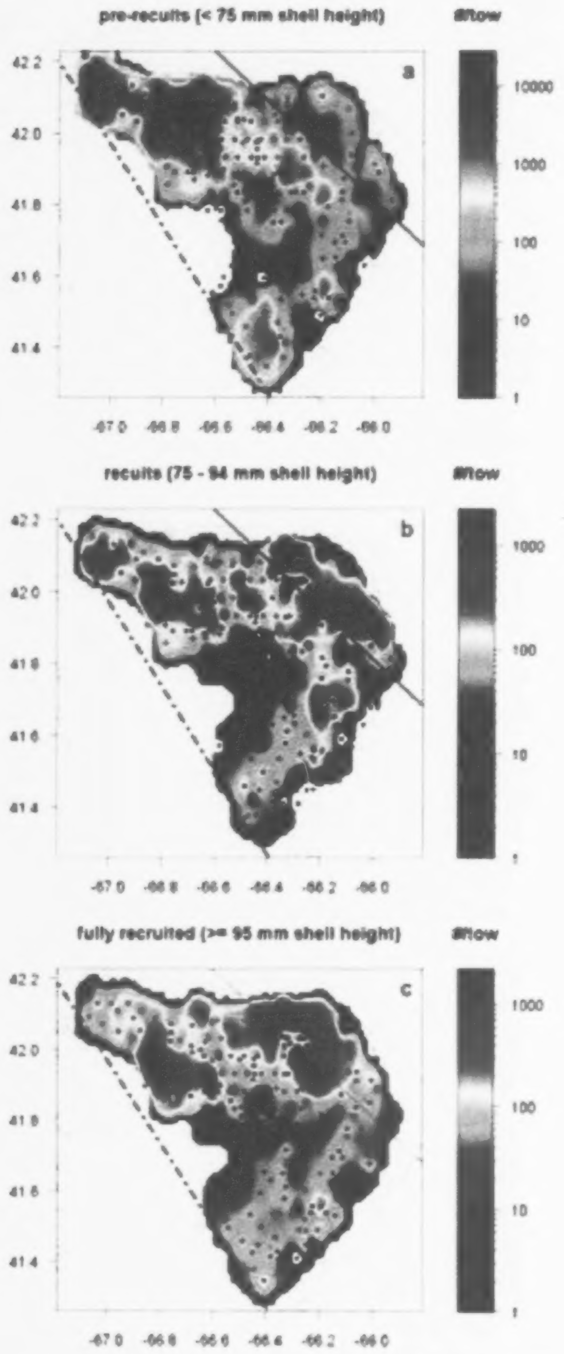

pre-recuits (< 75 mm shell height)
#/tow
a
10000
1000
100
10
1
42.2
42.0
41.8
41.6
41.4
-67.0
-66.8
-66.6
-66.4
-66.2
-66.0
recuits (75 - 94 mm shell height)
#/tow
b
1000
100
10
1
fully recruited (>= 95 mm shell height)
#/tow
c
1000
100
10
1

Figure 2-27. Distribution of sea scallop catches from the 2008 Georges Bank survey: (a) pre-recruits; (b) recruits; and (c) fully recruited (i.e. commercial sizes). Tow positions are represented by the black dots.

Population Structure Relative to Moratorium Area

Sea scallops on Georges Bank are generally found in three main aggregations: Northeast Peak, Great South Channel, and the southern edge of the Bank. The Northeast Peak aggregation supports an important fishery in eastern Canada. Sea scallops are sedentary once they have settled on the ocean bottom as spat. On the Northeast Peak, larval distribution has been shown to be positively related to water column stratification (Tremblay and Sinclair, 1990). Models that link larval biology and settlement numbers with the hydrodynamics and particle dynamics on Georges Bank indicate a significant exchange of larvae among the three main scallop aggregations (Tremblay et al., 1994; Tian et al., 2009). This, coupled with the presence of a partial gyre on Georges Bank that contributes to the retention of larvae on the Bank, supports the theory of a self-sustaining population of sea scallops on Georges Bank.

The Canadian portion of Georges Bank is managed using two zones. Zone A is the traditional scallop fishing ground and the more productive area. It comprises the majority of the area of the Canadian side of Georges Bank. The abundance of Georges Bank scallop has been at or above the 27 year median since 1999. Biomass of fully recruited scallops reached the highest levels in the time series from 2000-2002 and it remained well above the long term median in 2008. An extremely large cohort of pre-recruits was observed in 2008, which is expected to recruit to the fishery in 2010-2011. Higher commercial biomass levels are expected at this time (Figure 2-28).

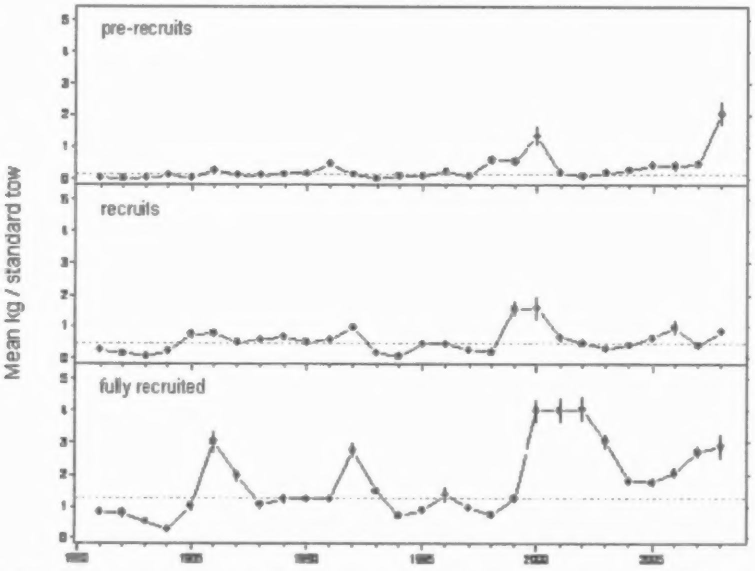


Figure 2-28. Sea scallop survey biomass indices for Georges Bank management Zone A as the mean weight per standard-tow (kg standard-tow^{-1}) for pre-recruit, recruit, and fully recruited scallops. The dashed lines are the 27-year median value for each size class.

Life History, Location, and Timing

The predominant spawning period for sea scallops on Georges Bank occurs from late August to October, although a brief spring spawning period from May to June is observed during most years (DiBacco et al., 1995). The annual recruitment for the species is variable, even though adult females are highly productive and produce approximately 50 million eggs per year per individual. For the first 6-8 weeks, larvae remain in the water column where they grow in size. After six to eight weeks of planktonic life, larvae settle to the bottom at a size of about 300 µm in diameter.

Known Vulnerabilities

Scallops, as filter-feeders, are vulnerable to the ingestion of contaminants and other particulate matter. Chronic contamination exposure to drilling wastes is believed to have strong sub-lethal effects on scallop growth and reproduction (Cranford et al., 1999). Exposure to drilling mud has the potential for up to 48 days of growth inhibition, although this is dependent on location and settling velocity of waste material (Cranford et al., 2003).

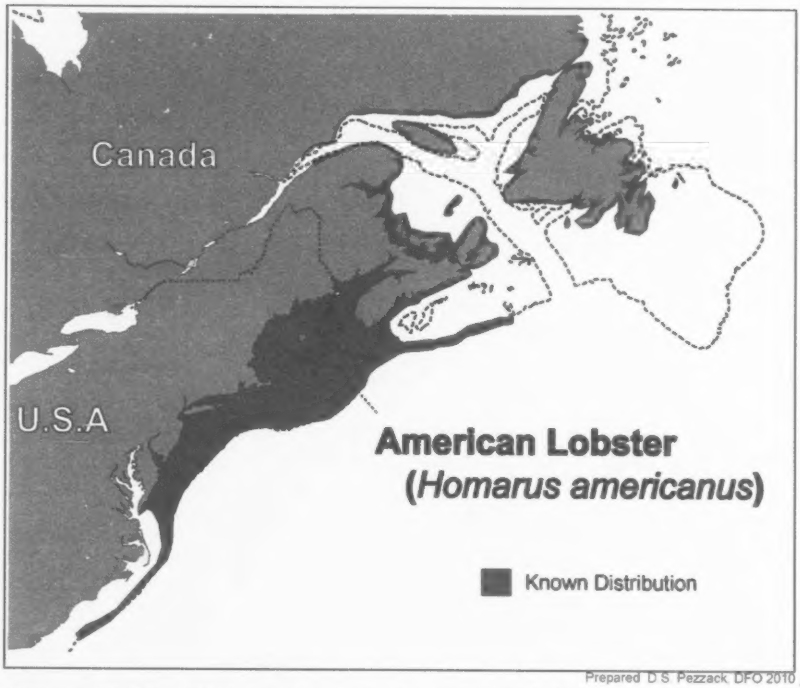
Status Designation

Georges Bank scallop is not listed pursuant to the *Species at Risk Act* (SARA) and has not been evaluated by the Committee on the Status for Endangered Wildlfe in Canada (COSEWIC).

2.7.3 Lobster

Distribution, Habitat, Abundance, and Predator and Prey

American lobster, *Homarus americanus*, are primarily found in coastal waters from southern Labrador to Maryland, with highest abundance found in the coastal waters of the southern Gulf of St. Lawrence and Gulf of Maine (Figure 2-29). Lobsters also inhabit the continental shelf and upper continental slope of the northwest Atlantic Ocean from the Scotian Shelf to South Carolina. This includes the deep central basins of the Gulf of Maine. In the offshore, lobster densities are typically 10-100 times less than those of the more productive coastal water regions (Uzmann et al., 1977a; Cooper and Uzmann, 1980). The highest abundance of lobsters on Georges Bank is found in canyons along the Bank's outer slope and, to a lesser extent, along the northeast edge (Figure 2-30).


Canada
U.S.A
American Lobster
(Homarus americanus)
■ Known Distribution

Prepared D.S. Pezzack, DFO 2010

Figure 2-29. Distribution of American lobster, *Homarus americanus*, in the Northwest Atlantic.

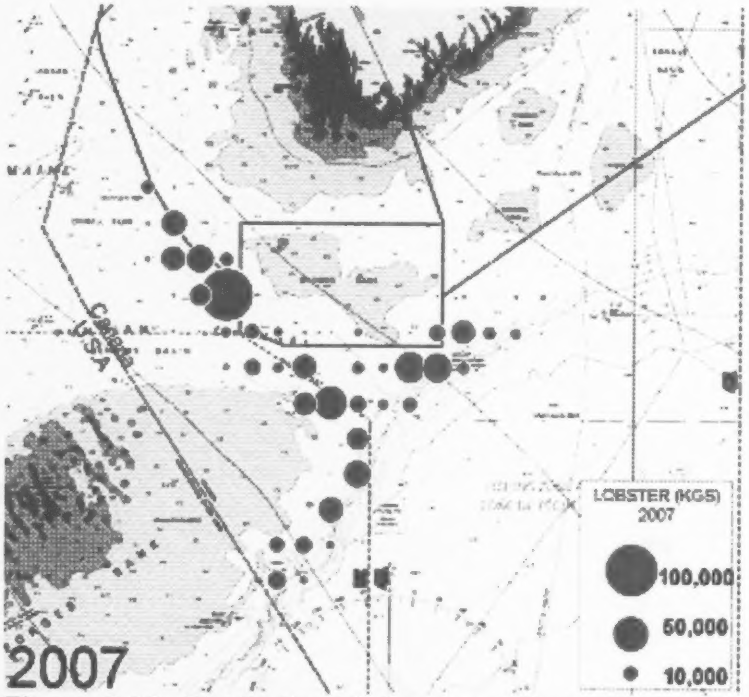

MAINE
Canada
USA
LOBSTER (KGS)
2007
100,000
50,000
10,000
2007

Figure 2-30. Distribution of American lobster landings by mass (kg) in Lobster Fishing Area (LFA) 41 in 2007. Data is aggregrated by 10 minute grids.

Lobster larvae are carnivorous, feeding primarily on copepods, decapod crustacean larvae, and fish eggs. Adult lobsters feed primarily on bottom dwelling invertebrates (e.g. crabs, polychaetes, mussels, periwinkles, sea urchins, brittle stars, and sea stars), as well as fishes and seaweeds (Carter and Steele, 1982; Elner and Campbell, 1987).

Canadian landings of lobster from Georges Bank have been relatively stable since 2000, with catch per unit effort (CPUE), both standardized and unstandardized, increasing through time (Pezzack et al., 2009) (Figure 2-31). The U.S. landings of the Georges Bank lobster fishery remained stable from 1981-2002 at an average of 1300 t. From 2003-2007, landings almost doubled, reaching a high of 2400 t in 2005, where it has since remained. The 2009 American assessment concluded that the Georges Bank stock has increased recently, with the current abundance and spawning stock biomass (Figure 2-32) being at record highs compared to the 26-year time series (ASMFC, 2009) (Figure 2-33). In contrast, exploitation is below the median value for the 22-year time series (ASMFC, 2009) (Figure 2-34).

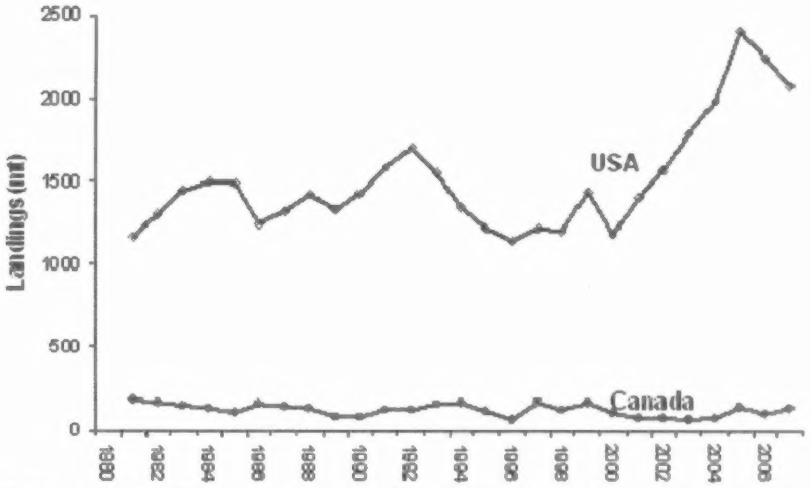


Figure 2-31. Georges Bank lobster landings (metric tones, mt) from Canadian LFA 41 and American offshore lobster fisheries.

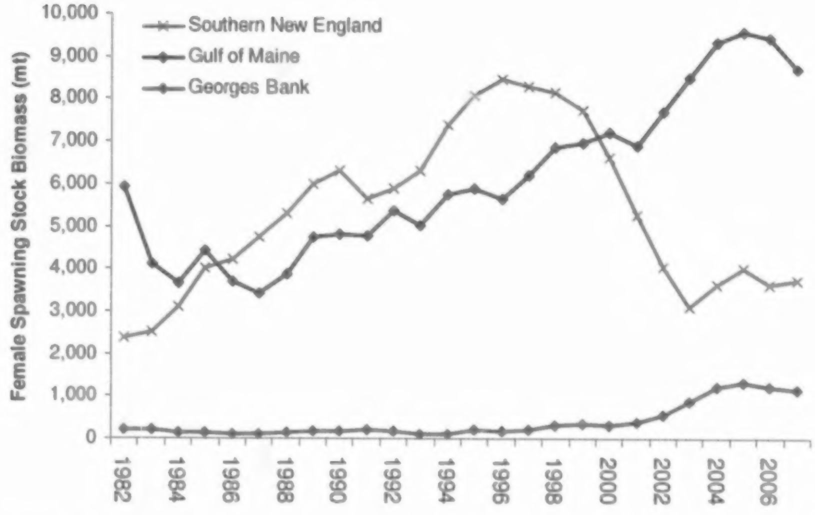


Figure 2-32. Estimates of lobster spawning stock biomass (mt) from the base case model (ASMFC, 2009).

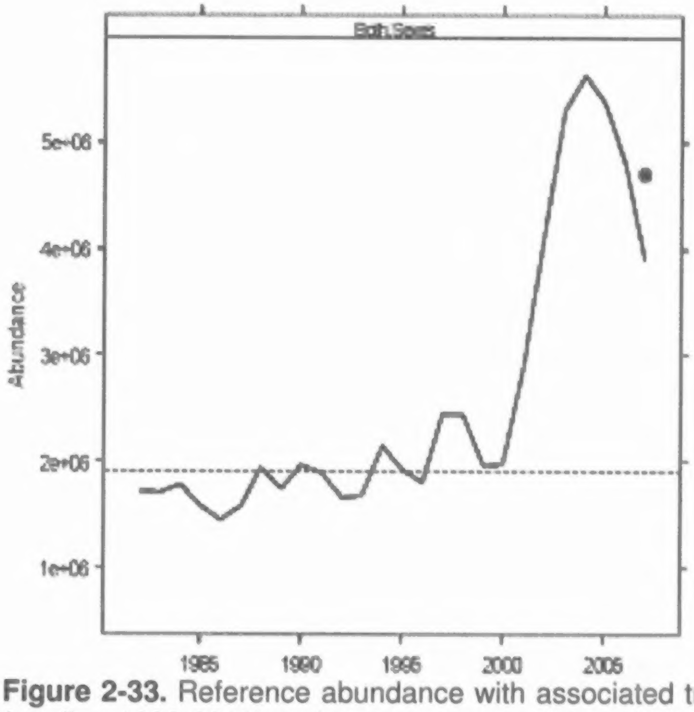


Figure 2-33. Reference abundance with associated trend based reference point (median 1982-2003) and status measure (mean 2005-2007) from the base case model for Georges Bank lobster (ASMFC, 2009).

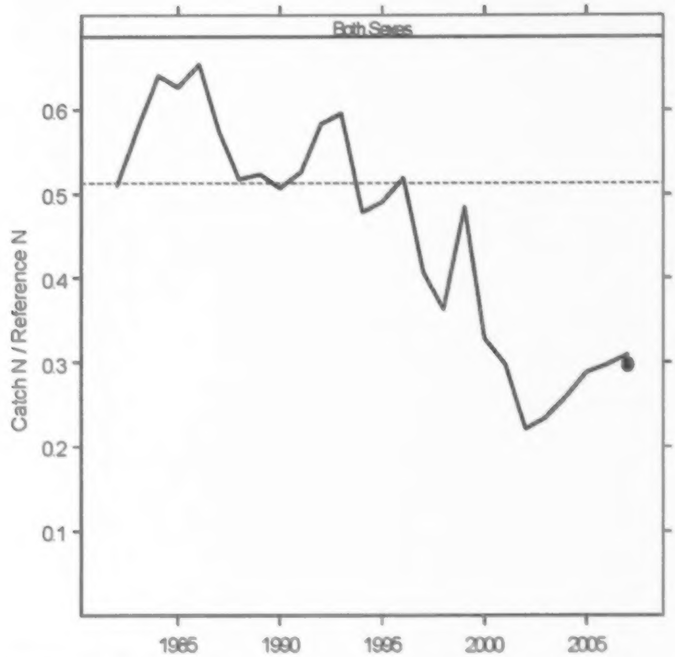


Figure 2-34. Annual effective exploitation rate, with associated trend based reference point (median 1982-2003) and status measure (mean 2005-2007) from the base case model for Georges Bank (ASMFC, 2009).

Population Structure Relative to Moratorium Area

In summer, lobsters in the Georges Bank region move from deeper waters surrounding the Bank (i.e. 300-700 m) to the shoal waters of the central plateau to moult and mate (Uzmann et al., 1977b; Pezzack and Duggan, 1987; Pezzack et al., 2009). The eggs are carried by the female for the next 10 months, after which they return to the shallow waters of the Bank and hatch the eggs the following summer. Migrations onto the Bank can range from a few kilometres up to 100 km in distance. The adult lobsters tend to remain in the vicinity of the Bank and mix little with other areas. This may result in distinct and unique populations. For example, genetic work using microsatellite markers has shown gene flow between lobsters from Georges Bank and Cape Cod, as well as the outer shelf south of the Great South Channel, but with barriers and low gene flow between Georges Bank lobsters and lobsters from coastal Maine and the Scotian Shelf (Kenchington et al., 2009).

It is not known what percentage of lobster larvae is retained by the partial gyre of Georges Bank, although pelagic lobster larvae have been observed on the northern edge of Georges Bank in July and August. This indicates some degree of off-bank movement (Harding et al., 1995; Harding et al., 2005). As such, a loss of some larvae off bank is expected, although the contribution of Georges Bank lobster to populations in the Gulf of Maine remains unclear.

Life History, Location, and Timing

The timing of summer migrations to mate and moult appears to be temperature dependent. The first hatching of lobster eggs on Georges Bank occurs in June and July (this precedes hatching on nearby Browns Bank and German Bank, which occurs in late July and early August). Newly-hatched larvae move to surface waters where they feed on a variety of planktonic species such as cladocerans and copepods, as they develop through four moult stages. After approximately a month in the water column, lobster larvae settle to the seabed and continue with a fifth moult stage. In winter, lobsters migrate back to deeper waters, although immature lobsters may remain on the shallow central plateau where they reside in sheltered, rocky areas and compacted sediment in which they can burrow.

The ecology, life cycle, and population dynamics of the lobster in deep waters near offshore banks is far from complete. For example, the specific locations of settlement and nursery grounds remain unknown. Smaller sizes (in trawl surveys) in the shoal water areas of Georges Bank suggest that this is the likely area of settlement but, to date, no methods have been developed to test this assumption (Pezzack et al., 2009). Some work is underway with settlement collectors although, so far, it is limited to shallow coastal waters with some initial tests in deeper coastal waters.

Known Vulnerabilities

Though vulnerable at all life history stages, lobsters are most vulnerable during the 30-60 day planktonic larval stages when they are at or near the surface. The vertical distribution of larvae is not well understood, but data shows Stage I-II are distributed throughout the upper mixed layer (i.e. generally the upper 15 m) (Harding et al., 1987; Xue et al., 2008), while post larvae are concentrated in the upper 2 m, and generally in the upper 0.5m (Annis, 2005). Previous studies on the effects of contaminants (e.g. heavy metals and hydrocarbons) on larvae lobster have demonstrated biochemical, growth, and development effects, including changes in respiration, growth, feeding rates, and development times (Derby and Capuzzo, 1984). In addition, studies on the effects of contaminants on juvenile and adult lobster have demonstrated changes in burrowing behaviour and quality, food detection, molting frequency, respiration, and growth rates (Atema et al., 1982; Derby and Capuzzo, 1984).

Physical barriers (e.g., pipelines) resting on the bottom may also create barriers to the seasonal migration of lobster, which is important for growth and reproduction. The degree of impact may depend on the shape, size, and surface texture of the barrier, degree of burial, and the amount of open area beneath the barrier, as it crosses areas of uneven seafloor. Last, limited research has examined the impact of noise on lobster. Lobster exposed to high and low sound levels demonstrated changes in feeding and serum biochemistry, with effects sometimes being observed weeks to months after exposure (Payne et al., 2007; Payne et al., 2008a).

Status Designation

American lobster is not listed pursuant to SARA and has not been evaluated by COSEWIC.

2.7.4 Crab

2.7.4.1 Deep-sea Red Crab

Distribution, Habitat, Abundance, and Predator and Prey

The deep-sea red crab, *Chaceon quinquedens*, is distributed along the continental shelf and slope of the western Atlantic. It is found between 200-1800 m water depth from Nova Scotia to Floride (Steimle et al., 2001). In Atlantic Canada, the deep-sea red crab is at the northern edge of its range, and populations are most dense on mud, sand and hard bottoms at water depths of 300-900 m and temperatures of 5-8°C (DFO, 1998). Red crabs are opportunistic feeders that feed on squid, demersal and mid-water fish, sponges, hydroids, gastroids molluscs, polychaetes, and crustaceans (Stehlik, 1993; Steimle et al., 2001). No information is available on the diet of red crab larvae, but it is thought that zooplankton is the primary component of the larval diet (Steimle et al., 2001). The distribution of deep-sea red crab on Georges Bank, based on results from DFO research surveys, is shown in Figure 2-35.

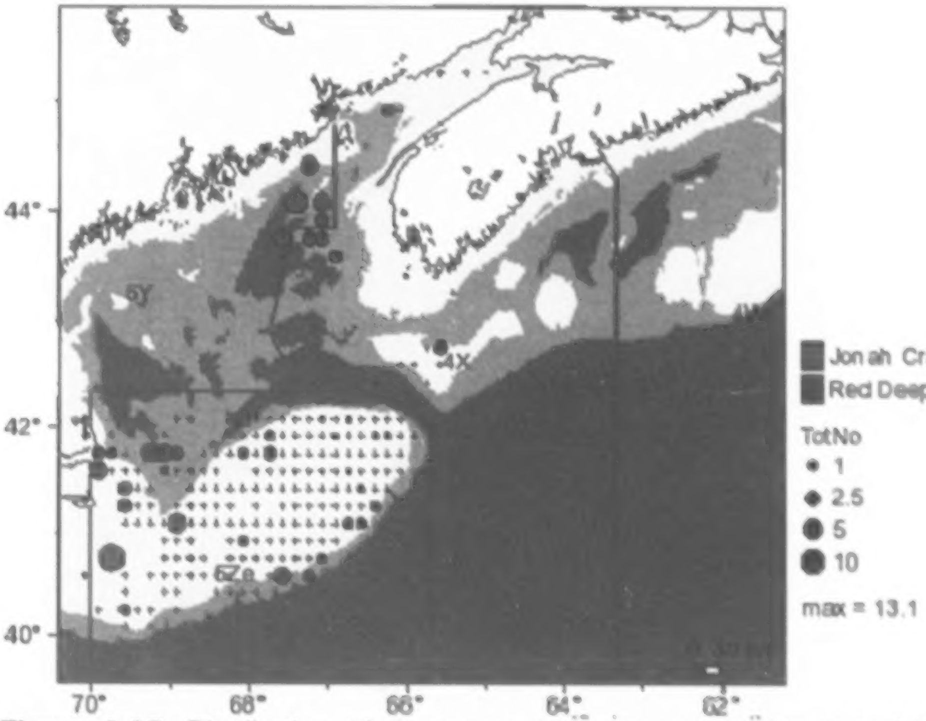


Figure 2-35. Distribution of deep-sea red crab and Jonah crab during DFO Georges Bank research surveys from 2002-2009.

Deep-sea red crab represents a data poor stock because they inhabit deep water, are rarely caught in trawl surveys, and little is known about their life history. The last assessment for red crab in the DFO Maritimes Region was completed by DFO in 1998. At that time, the offshore red crab fishing grounds were fully exploited with evidence of stock depletion on offshore banks. Catch rates have declined since the inception of the fishery, and the reduced landing and CPUE in 1997 suggest that red crab on Browns Bank may be depleted (DFO, 1998). Red crab in Canadian waters is at the northern edge of its range, and it is likely that much of the recruitment originates from the larger population in U.S. waters.

Sustained and reliable recruitment may not occur and, on the Scotian Shelf and northeast Georges Bank, it is fished as a pulse fishery by a small number of vessels. A 2003-2005 U.S. stock assessment indicated the biomass estimate of large male crab (greater than 114 mm carpace width) was approximately 13,800 t. This was 42% lower than 1974 estimates, while fishable male biomass, estimated to be 36,300 t, increased 5% over 1974 estimates. The current fishery, however, lands smaller red crabs in comparison to 1974. The estimated biomass of sexually-mature male and female red crab suggests a 29% and 244% increase from 1974, respectively (NEFSC, 2006a).

Population Structure Relative to Moratorium Area

Adult deep-sea red crabs are segregated incompletely by sex. Adult females generally inhabit shallower water than adult males, and juveniles tend to be deeper than adults, suggesting a deep-to-shallow migration as the crabs mature (NDPSWG, 2009). Tagging studies suggest red crabs move both vertically along the continental slope, covering a range of approximately 500 m, as well as laterally, covering an range of approximately 100 m (Steimle et al., 2001). Substantial numbers of red crab larvae have been collected from 12-270 km offshore on the Nova Scotia-Georges Bank area, with settlement thought to occur at the base of the continental shelf (DFO, 1998).

Life History, Location, and Timing

The deep-sea red crab is slow growing and reaches a maximum size of approximately 180 mm carapace width (CW). The size at maturity has been reported to primarily range from 80-130 mm CW (Steimle et al., 2001). Egg bearing females are present year-round off New England, with a peak incidence in November, and egg hatching is most prevalent from January to June. Females brood the eggs for up to nine months until the eggs hatch and the larvae are released into the water column (Steimle et al., 2001). The larvae require 23-125 days to develop through six stages before settling to the bottom. Settlement is thought to occur at the base of the continental shelf, with immediate upslope migration to warmer water likely occurring to enhance growth rates (DFO, 1998).

Known Vulnerabilities

No known vulnerabilities for deep-sea red crab.

Status Designation

Deep-sea red crab is not listed pursuant to SARA and has not been evaluated by COSEWIC.

2.7.4.2 Jonah Crab

Distribution, Habitat, Abundance, and Predator and Prey

Jonah crab, *Cancer borealis*, are found from Newfoundland to South Carolina and in the Bermuda Islands at depths ranging from the intertidal to 800 m. In the offshore waters of Nova Scotia, Jonah crab are found primarily at depths of 50-300 m and temperatures of 8-14°C (DFO, 2009b). Its substrate preference changes from rocky substrates inshore to silt and mud off the continental slope. Jonah crab are opportunistic feeders that feed on squid, demersal and mid-water fish, sponges, hydroids, gastroids, molluscs, polychaetes, and crustaceans

(Stehlik, 1993; Steimle et al., 2001). The distribution of Jonah crab on Georges Bank based on results from DFO research surveys is shown in Figure 2-35.

The offshore Jonah crab fishery began in 1995. Jonah crab is fished as a by-catch in the lobster fishery within LFA 41, more specifically Crowell Basin, Southwest and Southeast Browns Bank, Georges Basin, and Georges Bank. Abundance indicators (CPUE, number per tow in research vessel summer trawl surveys) and landings suggest that Jonah crab abundance has declined following the initiation of the fishery (Figure 2-36). Landings declined from 720 t in 1996-1997 to 14 t in 2007. There is insufficient information to evaluate production or recruitment trends for Jonah crab in LFA 41 (DFO, 2009b).

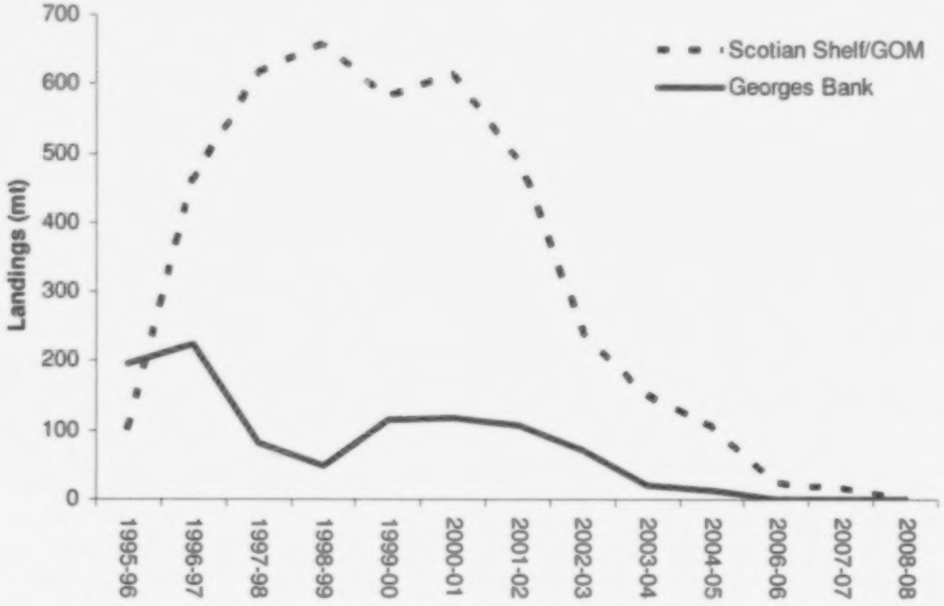


Figure 2-36. Jonah crab landings (mt) in the LFA 41 for the management of the Lobster/Jonah crab fishery.

Population Structure Relative to Moratorium Area

Stock structure and migratory behaviour of Jonah crab are poorly understood, and their ability to redistribute themselves over the fishing grounds is unclear (DFO, 2009b). There have been some indications of migrations. Inshore movement from spring through fall, followed in winter by emigration to deeper warmer water toward the offshore edges of the shelf of Georges Bank and the Middle-Atlantic, has been reported (Stehilk et al., 1991). Size and sexual segregation with depth were reported in Virginia (DFO, 2009b). It is unclear, however, whether similar seasonal migrations and segregations occur in the Georges Bank area.

Life History, Location, and Timing

Very little biological information exists for Jonah crab in waters off of Nova Scotia. Knowledge of life history is geographically limited to waters off of New England and Chesapeake Bay. Preliminary analysis of Jonah crab maturity on the Scotia Shelf has shown that maturity of 50% males and females occurred at 128 mm and 92 mm CW, respectively (DFO, 2009b). The spawning period in the Mid-Atlantic Bight is suggested to be during late winter to early spring (DFO, 2009b). The female broods eggs in the swimmerets under the abdomen. The larvae develop through several plankton stages in the water column before settling to the bottom.

Known Vulnerabilities

No known vulnerabilities for Jonah crab.

Status Designation

The Jonah crab is not listed pursuant to SARA and has not been evaluated by COSEWIC.

2.7.5 Squid

2.7.5.1 Northern Shortfin Squid

Distribution, Habitat, Abundance, and Predator and Prey

The northern shortfin squid, *Illex illecebrosus*, is a highly migratory and transboundary species that is distributed in the northwest Atlantic from Newfoundland to Florida. It is considered to constitute a single stock throughout its range. The northern component of the stock extends from Newfoundland to the southern Scotia Shelf and the southern component extends from the Gulf of Maine to Florida (Hendrickson and Holmes, 2004). The species inhabits the continental shelf and slope waters from Cape Hatteras to Georges Bank and the Scotian Shelf primarily during spring through autumn. During late autumn, squid migrate off the continental shelf and southward. Species distribution and abundance are strongly related to oceanographic factors. During the spring, squid are most abundant in water depths of 120-400 m and temperature range of 10-14°C. In autumn, squid are most abundant in a bottom temperature range of 8-13°C, with abundance increasing with depth between 31-140 m and a secondary peak between 200-300 m (Hendrickson and Holmes, 2004).

Northern shortfin squid feed primarily on fish and crustaceans, but cannibalism of small individuals by larger females also occurs, particularly during autumn. They exhibit diel vertical migrations, and both juveniles and adults feed primarily at night in the upper levels of the water column. An ontogenetic shift in diet from a predominance of crustaceans to fish and squid is evident in squid from both components. Fish prey consists of early life history stages of Atlantic cod, Arctic cod and redfish, sand lance, mackerel, Atlantic herring, haddock, sculpin, and longfin inshore squid (Hendrickson and Holmes, 2004).

The abundance of northern shortfin squid commercially-exploited in the U.S. Gulf of Maine area is highly variable from year to year, due to their short life span and highly migratory nature. Abundance appears to be closely tied with that of their prey, competitors, and shifts in the geographic position of the Gulf Stream and related fronts. In NAFO Division 4, a period of high productivity and relative abundance from 1976-1981 occurred between two low productivity periods of 1970-1975 and 1982-2004. A large increase in the biomass index during 2004 was followed by a sharp decline of 0.7 kg per tow in 2005 that was well below the 1982-2004 average of 3.0 kg per tow (NEFSC, 2006b). In NAFO Divisions 5 and 6, survey results indicate that periods of high relative abundance occurred from 1976-1981 and 1987-1990, averaging 18.8 and 19.5 squid per tow, respectively. An intermediate level of abundance occurred during 1991-1998, averaging 8.7 squid per tow. Survey indices increased after 1999 and attained a record high in 2003, but they declined sharply in 2004 to the level observed in 2002. In 2005, survey indices increased slightly (Hendrickson, 2004).

Population Structure Relative to Moratorium Area

Seasonal distribution patterns suggest that annual migrations from the slopewater onto the shelf in the spring and off the shelf in the autumn occur simultaneously along the entire length of the continental shelf edge. Tagging studies have demonstrated a south-eastward migration of individuals during autumn. Georges Bank is on their migration route to the Gulf of Maine, and it may serve as an important feeding area. The migration patterns between northern and southern stock components remain unknown, however, and the offshore fraction of the population is not well understood (Hendrickson, 2004).

Life History, Location, and Timing

Northern shortfin squid live for less than one year (115-215 days), exhibit variable growth rates, high natural mortality rates, and a protracted spawning season in which overlapping microcohorts continuously enter the populations throughout the year over a wide geographic area. Spawning occurs throughout most of the year from October through June. The only confirmed spawning area is located in the Mid-Atlantic Bight at depths of 113-377 m, where the winter cohort spawns during late May (Hendrickson, 2004). Spawning may also occur offshore in the Gulf Stream/Slope Water frontal zone (O'Dor and Balch, 1985) and south of Cape Hatteras during winter (Dawe and Beck, 1985).

Shortfin squid is a semelparous, terminal spawner with spawning and death occurring within several days of mating. Female squid may release multiple neutrally buoyant, gelatinous egg balloons with hatching occurring 8-16 days thereafter (Hendrickson and Holmes, 2004). Larvae may remain within the remnants of the egg mass to utilize the nutrients as a food source. Larvae are carried northward by the Gulf Stream and live in the frontal zone between the Gulf Stream and slope water until they reach approximately 10 cm in length (Dawe and Hendrickson, 1998). Size and age-at-maturity increase with latitude and are correlated with decreases in water temperature (Hendrickson, 2004).

Known Vulnerabilities

Squid demonstrated a strong startle response to nearby air-gun start up and evidence that they would significantly alter their behaviour at an estimated 2-5 km from an approaching, strong seismic source (McCauley et al., 2000a).

Status Designation

Northern shortfin squid is not listed pursuant to SARA and has not been evaluated by COSEWIC.

2.7.5.2 Longfin Inshore Squid

Distribution, Habitat, Abundance, and Predator and Prey

Longfin inshore squid, *Loligo pealeii*, a schooling species, are distributed from Newfoundland to the Gulf of Venezuela. The principal concentrations, however, occur from Georges Bank to Cape Hatteras. The population is considered to constitute a single stock throughout its range (Brodziak, 1995). Adult longfin inshore squid inhabit the continental shelf and upper slope to depths of 400 m, although depth varies seasonally. In spring, they occur at depths of 110-200 m, in summer and fall they inhabit inshore waters as shallow as 6-28 m, and in winter they inhabit offshore waters to depths of 365 m. They are found on mud or sand/mud substrate at surface temperatures ranging from 9-21°C and bottom temperatures ranging from 8-16°C (Jacobson, 2005).

Longfin inshore squid form large schools based on size prior to feeding and make diurnal vertical migrations up through the water column at night. Their diet changes with size. Small immature individuals feed on planktonic organisms including euphausiids, arrow worms, small crabs, polychaetes, and shrimp, while larger individuals feed on crustaceans, small fish, and squid. Fish prey species include silver hake, mackerel, herring, menhaden, sand lance, bay anchovy, menhaden weakfish, and silversides. Seasonal and inshore/offshore differences in diet were reported for longfin inshore squid. In offshore waters in the spring, the diet is composed of crustaceans (mainly euphausiids) and fish. During the fall, in inshore waters, the diet is composed almost exclusively of fish (Jacobson, 2005).

Annual autumn relative abundance indices are highly variable, partially because relative abundance is affected by oceanographic conditions (Hendrickson and Jacobson, 2006). During 1967-2005, survey indices varied with little trend, except that relative abundance was consistently below the time series average during 1968-1972 and above the time series average during 1999-2002. After 2002, relative abundance declined and was below average in 2005. The stock found between the northern edge of Georges Bank to Cape Hatteras was last assessed by the NEFSC in 2001. Production model results indicated that the quarterly biomass ranged between 14,000-27,000 t and averaged 21,800 t during 1987-2000 (Hendrickson and Jacobson, 2006).

Population Structure Relative to Moratorium Area

Longfin inshore squid undergo seasonal migrations that appear to be related to bottom water temperatures. They migrate offshore along the edge of the continental shelf during late autumn and return inshore during the spring and early summer (Jacobson, 2005). When inshore waters are coldest during winter and early spring, the population concentrates along the outer edge of the shelf. The inshore movement to the shelf areas takes place when water temperatures are increasing, which begins in the south and proceeds north along the coast. Spawning has been reported to occur during this migration. In Canadian waters, spawning has been reported from early spring and late summer on the Scotian Shelf and Georges Bank (Jacobson, 2005).

Life History, Location, and Timing

Longfin inshore squid have a lifespan of less than one year (approximately 9 months), grow rapidly, and are sexually dimorphic. Males grow more rapidly and reach larger sizes at age than females. In addition, growth is dependent on temperature and is highest for individuals hatched in summer (Brodziak and Macy, 1996). Longfin inshore squid spawn year round with seasonal peaks that vary between years and geographic areas, though most eggs are spawned in May and hatched in July. Spawning has been reported from August to September in the Bay of Fundy, May to August in New England waters, late spring to early summer in the Middle Atlantic, and early spring and late summer on the Scotian Shelf and Georges Bank (Jacobson, 2005). Females lay clusters of gelatinous egg capsules, each containing 150-200 eggs, on rocks and aquatic vegetation usually at depths less than 50 m. The eggs hatch in 11-27 days, depending on temperature, to produce planktonic larvae that move deeper as they grow. The shift from inhabiting surface waters to a demersal lifestyle occurs at 45 mm CW (Jacobson, 2005).

Known Vulnerabilities

Squid demonstrated a strong startle response to nearby air-gun start up and evidence that they would significantly alter their behaviour at an estimated 2-5 km from an approaching, strong seismic source (McCauley et al., 2000a).

Status Designation

Longfin inshore squid is not listed pursuant to SARA and has not been evaluated by COSEWIC.

2.8 FINFISH

This section describes finfish species of commercial value, species with COSEWIC or SARA status, or other finfish species considered of interest to this marine ecosystem overview. Select finfish species are summarized in the Appendix.

2.8.1 Herring

Distribution, Habitat, Abundance, and Predator and Prey

Atlantic herring, *Clupea harengus*, range from Labrador to Cape Hatteras in the western Atlantic (Figure 2-37). Herring is a pelagic schooling species known to undertake extensive seasonal migrations for summer feeding and over-wintering, but it can be found almost year round in most areas. Adult herring are assumed to home to native spawning grounds where they aggregate annually for spawning. Major spawning areas are restricted to the northern regions between Cape Cod and northern Newfoundland (Scott and Scott, 1988). Bottom habitat is critical to spawning and varies from region to region. Typically, spring spawners spawn in near shore shallow waters, while fall spawners spawn in offshore deeper water.

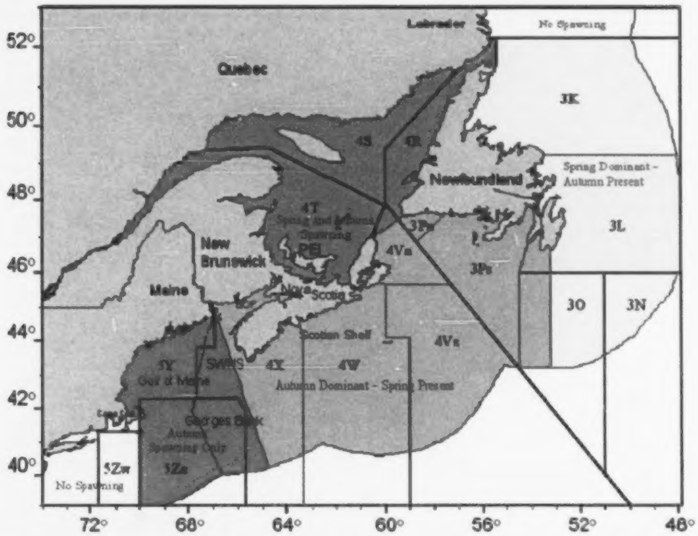

52°
50°
48°
46°
44°
42°
40°
72°
68°
64°
60°
56°
52°
48°
Labrador
No Spawning
Quebec
3K
4S
4R
Newfoundland
Spring Dominant - Autumn Present
4T
Spring and Autumn Spawning
PEI
New Brunswick
3Pn
4Vn
3Ps
3L
Maine
Nova Scotia
3O
3N
Scotian Shelf
4Vs
5Y
Gulf of Maine
SWNS
4X
4W
Autumn Dominant - Spring Present
Georges Bank
Autumn Spawning Only
5Zw
5Ze
No Spawning

Figure 2-37. Distribution and spawning strategy of Atlantic herring stocks along the western Atlantic (Melvin et al., 2009).

Atlantic herring are a key forage species on Georges Bank. They are critical to the transfer of energy from one trophic level to another in the ecosystem. Almost every marine fish species in the region consumes herring at some stage in their life cycle. The main food sources for herring are the copepods *Pseudocalanus sp.*, *Paracalanus parvus*, and *Centropages typicus* (Cohen and Lough, 1983). The adult diet is dominated by euphausiids, chaetognaths, and copepods (Bigelow and Shroeder, 1953). Smaller juvenile herring (42 -130 mm) eat larval stages of *Calanus* along with the copepods *Centropages* and *Pseudocalanus* and the larvae of mysids and decapods. Larval herring (12-42 mm in length) prefer *Pseudocalanus* at all of its stages, as well as the eggs and larvae of other copepods. Yolk-sac larvae (5-7 mm in length) and larvae up to 12 mm in length consume whatever zooplankton of appropriate size are abundant, including the eggs and larvae of ctenophores, siphonophores, polychaetes, and chaetognaths.

The Georges Bank herring stocks collapsed in the late 1970s due to foreign and domestic fleet over-fishing and poor recruitment. Herring was virtually absent on the Bank until the early 1980s. From the late-1980s to mid-1990s, the stock continued to rebuild and gradually reoccupied its historical spawning range. The stock has remained at a relatively high level since 1997. Georges Bank and the Gulf of Maine herring are assessed as a stock complex. In recent years, herring from Georges Bank are thought to contribute more than 80% of adult biomass to the total Gulf of Maine stock complex (Overholtz et al., 2004; Melvin and Stephenson, 2007). Figure 2-38 exhibits the trends in biomass and recruitment for the herring stock complex. Stock biomass (2+, January 1) increased steadily from about 111,600 t in 1982 to approximately 830,000 t in 1997. It has fluctuated since then and was estimated to be 652,000 t at the beginning of 2008 (Figure 2-38). Recruitment at age 2 from the 2004 and 2006 year classes appeared weaker than the long-term (1967-2005) average of 2.3 billion fish. The estimated 2005 year-class abundance is considered to be an above average abundance of 3.3 billion fish.

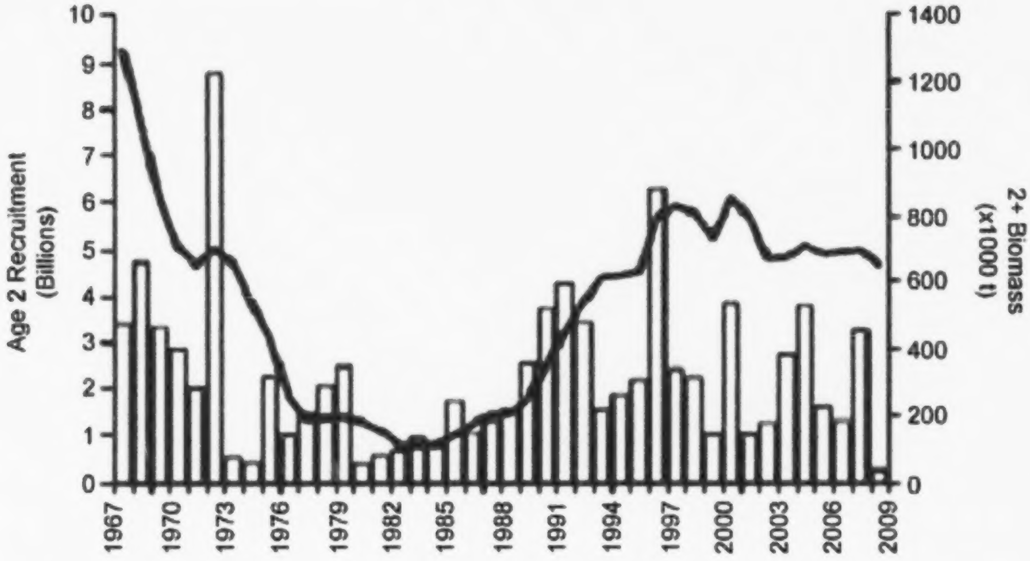


Figure 2-38. Age 2 recruitment (bars) and Age 2+ biomass (line) per year for the Gulf of Maine-Georges Bank herring stock complex (TRAC, 2009a).

Population Structure Relative to Moratorium Area

Herring populations of the western Atlantic exhibit considerable discreteness and limited connectivity that, on a temporal and spatial scale, is relevant to resource management, the ecosystem, and offshore development. This implies that activities that impact one population may have a limited impact on the others, even though they interact during non-spawning periods. Georges Bank herring undertake extensive annual migrations from their southern over-wintering locations to their feeding and spawning grounds on Georges Bank during the summer and fall. Herring from Georges Bank and the Gulf of Maine, which move south of Cape Cod during mid- to late-winter, begin migrating from their over-wintering areas to the southern part of Georges Bank with their numbers increasing as summer approaches. The spawning distribution extends along the entire northern reach from the Great South Channel to the Northeast Peak. Herring remain on the Bank for feeding and spawning until late-October to early-November when they disperse and slowly move southward to over-wintering areas. Bottom trawl survey catches demonstrating the distribution of adults during the spawning period (i.e. September-November) are shown in Figure 2-39. They can be considered a proxy for the spatial scale of the spawning area about the region (Melvin and Stephenson, 2007).

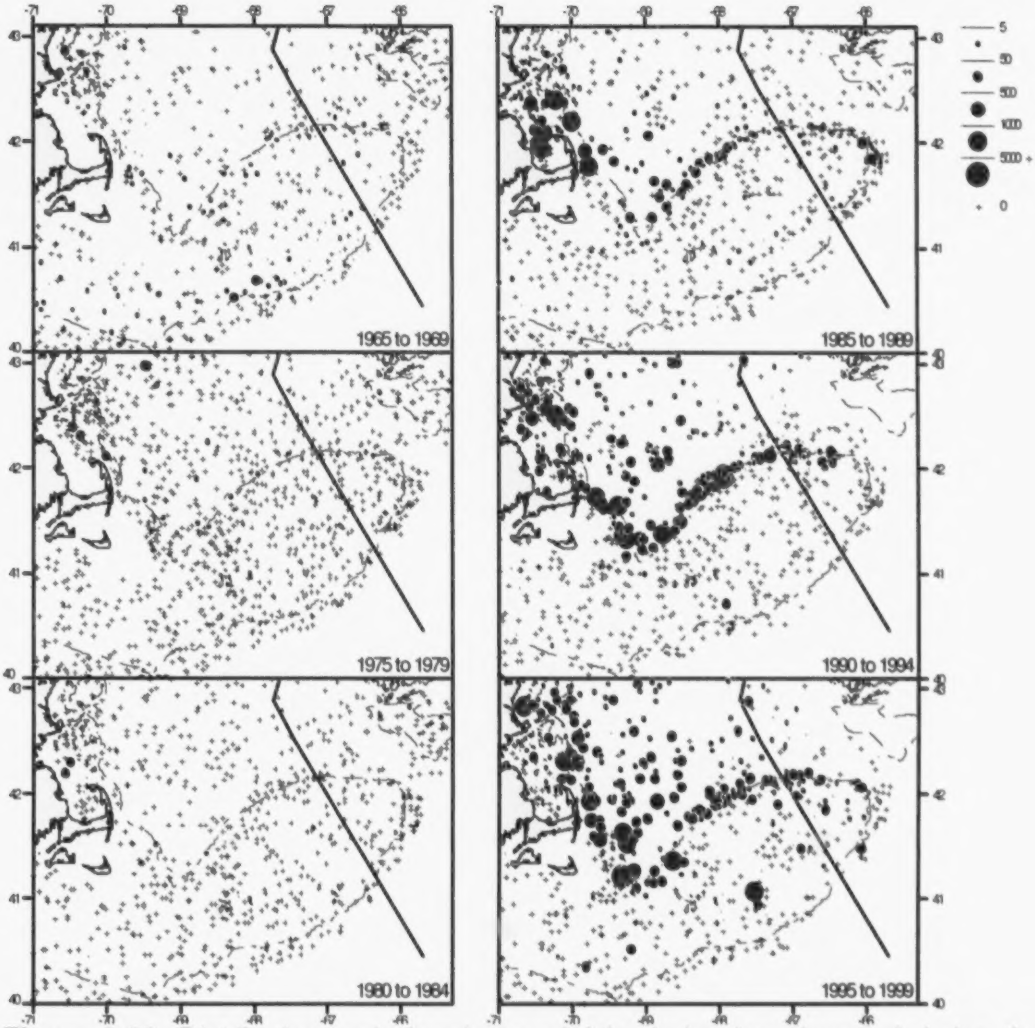

1965 to 1969
1975 to 1979
1980 to 1984
1985 to 1989
1990 to 1994
1995 to 1999
5
50
500
1000
5000 +
0
-71
-70
-69
-68
-67
-66
43
42
41
40

Figure 2-39. Distribution and abundance of Atlantic herring observed during the autumn U.S. and Canadian bottom trawl surveys on Georges Bank and surrounding areas for selected 5 year intervals. The numbers of fish per tow are scaled according to the adjacent key. The distribution in recent years is similar to that observed from 1995-1999 (Melvin and Stephenson, 2007).

Life History, Location, and Timing

Herring are bottom spawners. Male and female fish aggregate annually at specific locations to spawn over a period of 1-1.5 months. Spawning occurs in waves, and multiple spawning events can occur at the same location during a spawning season. The eggs are negatively buoyant and adhesive, and attach to the gravel substrate or benthic vegetation for 10-12 days before hatching, depending upon water temperature (Figure 2-40). Once hatched, larval herring become pelagic and can be found throughout the water column.

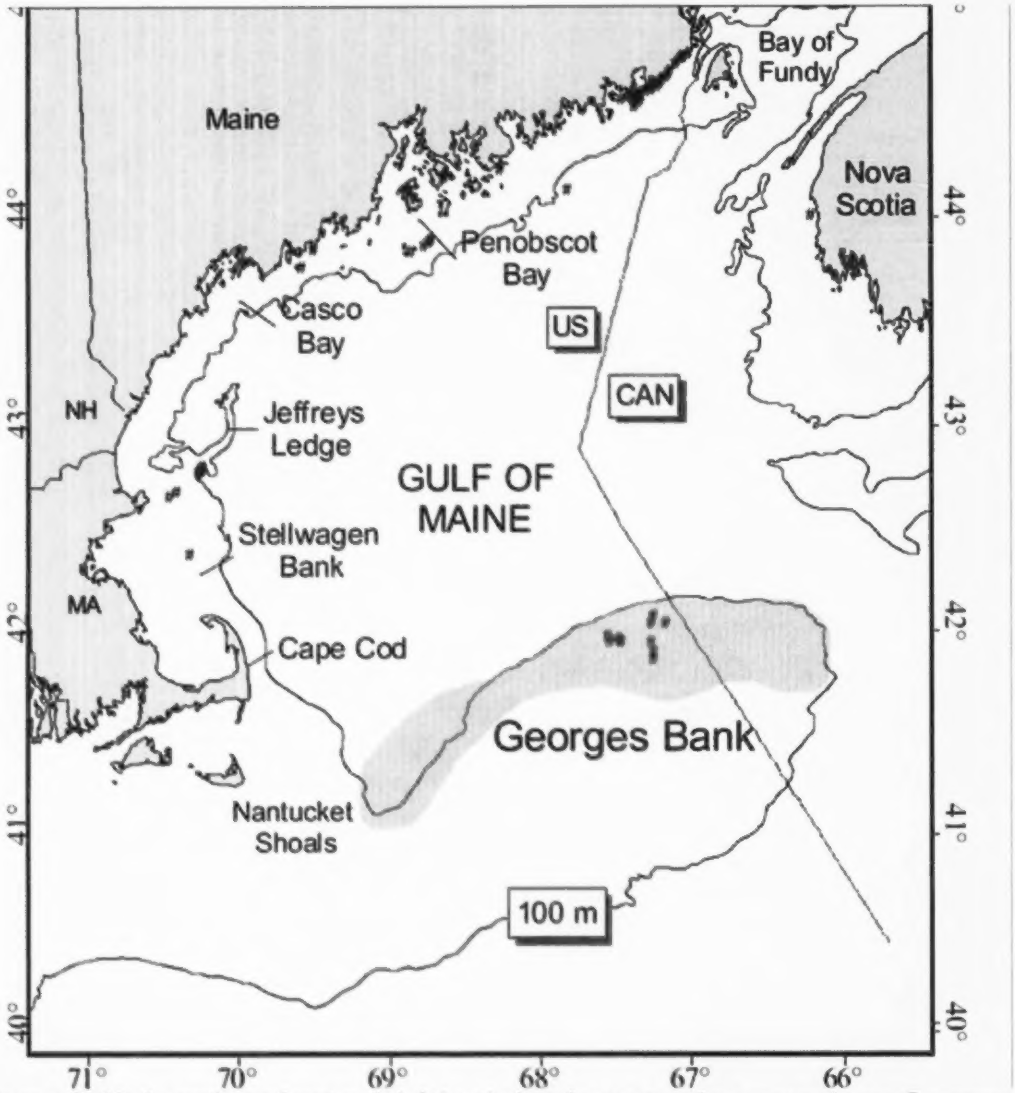

Maine
Bay of Fundy
Nova Scotia
Penobscot Bay
Casco Bay
US
CAN
NH
Jeffreys Ledge
GULF OF MAINE
Stellwagen Bank
MA
Cape Cod
Georges Bank
Nantucket Shoals
100 m
44°
43°
42°
41°
40°
71°
70°
69°
68°
67°
66°

Figure 2-40. Location of potential Atlantic herring spawning grounds on Georges Bank (grey) and the location of egg observations on the sea bed, as indicated by the number sign (#) (Stevenson and Scott, 2005).

On Georges Bank, the larval stage (October-March) lasts up to 6 months, after which they metamorphose into juvenile fish at a length 40-50mm. The distribution of larvae is consistent with the general winter circulation patterns. A large portion of the herring larvae remain on the Bank throughout the larval stage, including the Canadian portion (Figure 2-41). There is little, if any, dispersion into the coastal waters of the Gulf of Maine. Some larvae from Nantucket Shoals and Georges Bank drift to the southwest as far south as New Jersey (Lough et al., 1985; Stevenson and Scott, 2005).

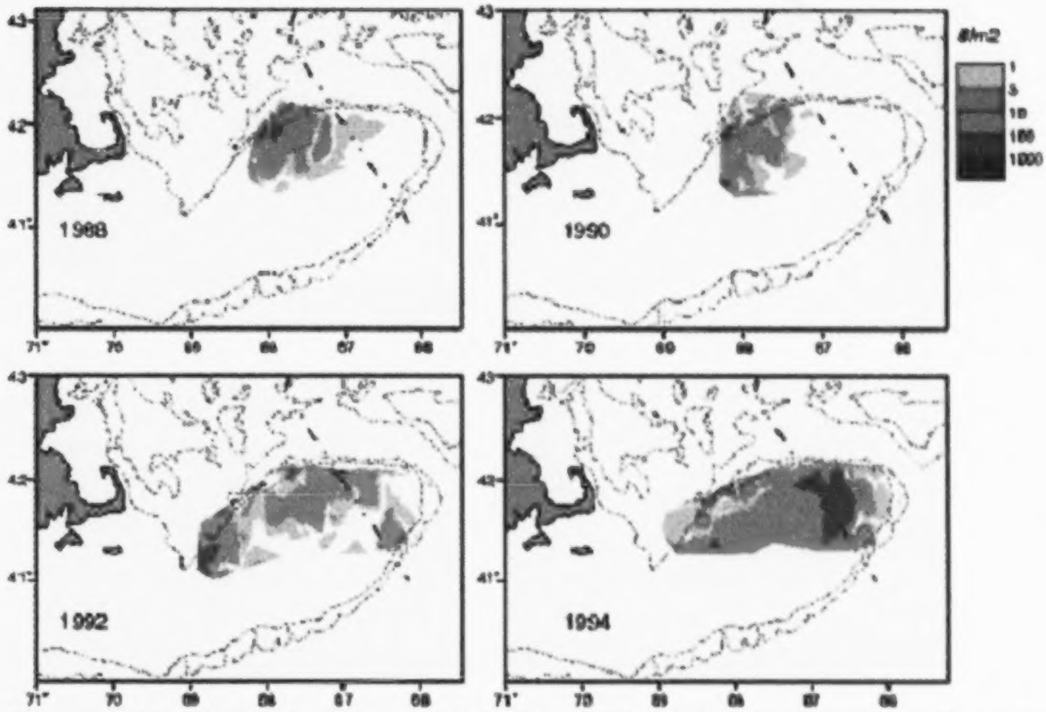


Figure 2-41. Distribution of recently hatched Atlantic herring larvae on Georges Bank from 1988-1994. The data represent the most recent Canadian larval data available. The annual larval survey on Georges Bank was concluded in 1996 (Melvin and Stephenson, 2007).

Juvenile herring from the Gulf of Maine and coastal Maine are known to migrate north during the summer to waters of southern New Brunswick, where they make an unknown contribution to the weir fishery. Georges Bank juvenile herring can be found on the Bank throughout the year, but many are thought to move inshore to coastal Maine and the northwestern portion of the Bay of Fundy. This large nursery area, with fish from several stocks, supports one of the oldest fisheries in Atlantic Canada.

Known Vulnerabilities

Herring is known to concentrate their spawning in relatively small and select locations. As such, they are vulnerable to any activities that interact with, disturb, or contaminate the ocean bottom. In addition, herring can detect a broad range of acoustic frequencies, likely, better than most fish. This suggests that noise may have an impact on their behaviour by altering migration patterns, disrupting spawning, and/or changing feeding behaviour. Changes in behaviour may not only affect herring but also other species in the ecosystem that depend on herring as forage.

Status Designation

Herring is not listed pursuant to SARA and has not been evaluated by COSEWIC.

2.8.2 Mackerel

Distribution, Habitat, Abundance, and Predator and Prey

Atlantic mackerel, *Scomber scombrus,* is a small schooling pelagic fish species. It is found on both sides of the North Atlantic Ocean, including the Baltic Sea. In the western Atlantic, Atlantic mackerel range from Labrador to Cape Hatteras (Figure 2-42). There is thought to be two main spawning components. In Canadian waters, there is a northern group that spawns mainly in the southern Gulf of St. Lawrence during the months of June and July. This spawning period is preceded by a long migration that begins early in spring in the Gulf of Maine and Georges Bank area (thought to be initiated when water temperatures reach approximately 8 ºC). In U.S. waters, there is a southern group that spawns primarily in the Mid-Atlantic Bight during the months of April and May. Both groups winter between Sable Island and Cape Hatteras in waters generally warmer than 7 ºC (Studholme et al., 1999). Mackerel are opportunistic feeders and prey most heavily on crustaceans, such as copepods, krill, and shrimp. They also eat squid and some fish. They are preyed upon by a large number of fish and cetacean species (Studholme et al., 1999).

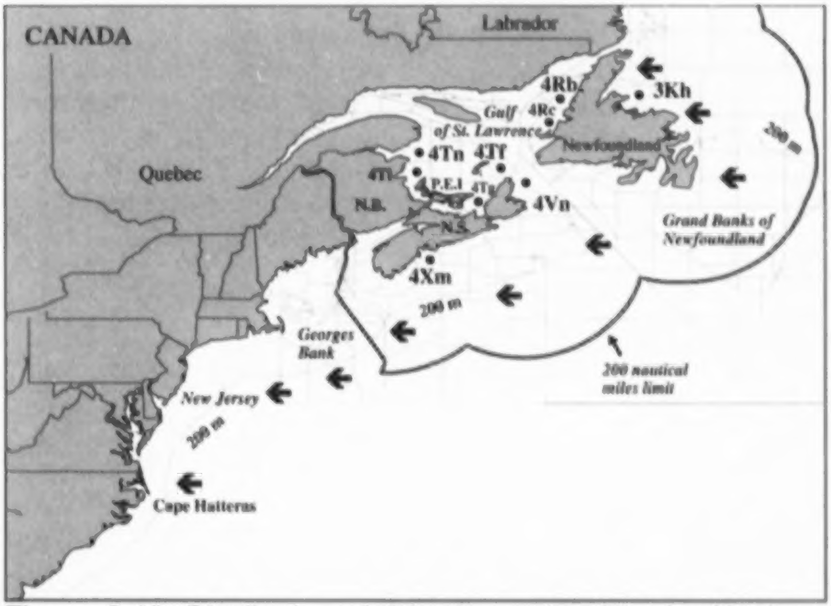

CANADA
Labrador
Quebec
4Rb
3Kh
Gulf of St. Lawrence
4Rc
Newfoundland
200 m
4Tn
4Tf
4Tl
P.E.I
4Tg
N.B.
4Vn
N.S.
Grand Banks of Newfoundland
4Xm
200 m
Georges Bank
200 nautical miles limit
New Jersey
200 m
Cape Hatteras

Figure 2-42. Distribution of Atlantic mackerel in the Northwest Atlantic (DFO, 2004a).

The Atlantic mackerel stock is thought to have collapsed in the late 1970s due to foreign fleet fishing efforts. Overall, spawning stock biomass has increased since 1978 and the stock as a whole is thought to have recovered in the late 1980s and 1990s. There was a very strong year-class of mackerel in 1999, but more recent year-classes do not appear to have been as strong. The northern component of mackerel that spawn in the southern Gulf of St. Lawrence has shown signs of a change in distribution, potentially in response to changes in water temperature. For the Gulf of St. Lawrence spawning component, there has been a reduction in the daily and total egg production since 2002. In 2007, spawning biomass was estimated at 76,532 t, which represents one of the lowest values of the series (NEFSC, 2006b; DFO, 2008b). Recent surveys also show an apparent lack of older fish.

Population Structure Relative to Moratorium Area

Mackerel are not caught in significant quantities in the Georges Bank bottom trawl survey, though they are thought to over-winter in the deeper waters of the continental shelf with migrations through this area heading north in spring and south in the fall. When they are caught in the survey, they tend to be found along the edges of the Bank (Figure 2-43).

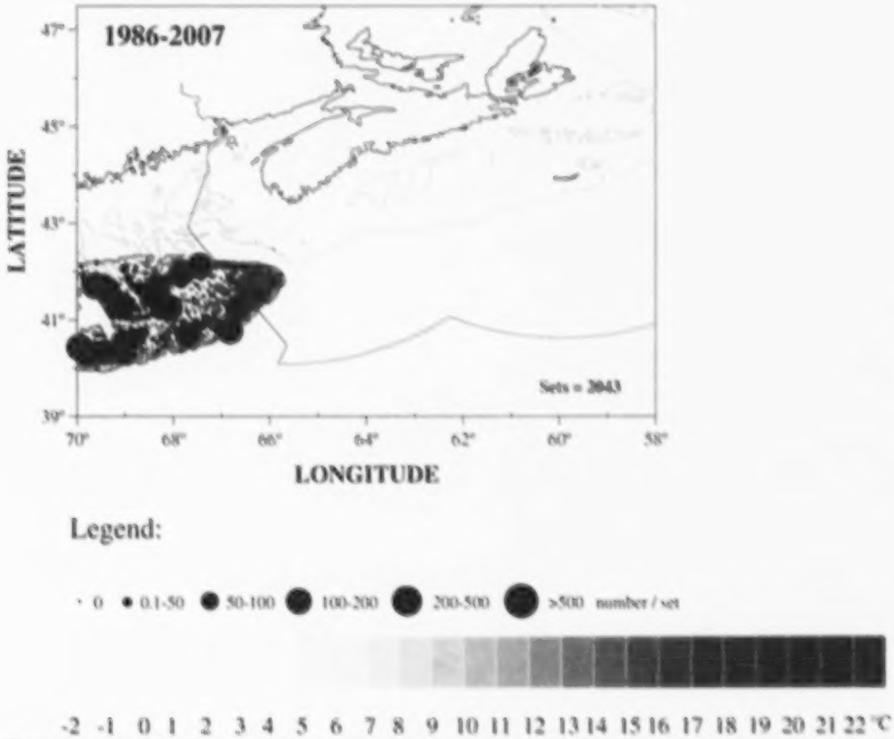

1986-2007
LATITUDE
47°
45°
43°
41°
39°
70°
68°
66°
64°
62°
60°
58°
LONGITUDE
Sets = 2043
Legend:
● 0
● 0.1-50
● 50-100
● 100-200
● 200-500
● >500
number / set
-2 -1 0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 °C

Figure 2-43. Composite map of mackerel catches by bottom trawl on Georges Bank from 1986-2007.

Life History, Timing, and Locations

Atlantic mackerel have a life span of approximately 20 years. Their growth is rapid and they can reach a maximum size of 42 cm in length and weight of 1 kg. They reach maturity between ages 2-3. Mackerel spawn between 5-7 batches of eggs per year. Eggs generally float in the surface water and hatch in 4-7.5 days depending on water temperature (Studholme et al., 1999).

Known Vulnerabilities

Mackerel eggs float in surface waters of temperatures 9 ºC and higher and, as such, may be susceptible noise, oil, or other contaminants. Mackerel do not have a swim bladder and are not believed to be as sensitive to sound pressure as those fish species with a swim bladder.

Status Designation

Atlantic mackerel is not listed pursuant to SARA and has not been evaluated by COSEWIC.

2.8.3 Sand Lance

Distribution, Habitat, Abundance, and Predator and Prey

Two species of sand lance occur in the northwest Atlantic, the American sand lance (*Ammodytes americanus*) and the northern sand lance (*Ammodytes dubius*). These species are similar, thus difficult to distinguish (Breeze et al., 2002). Sand lance is a bottom dwelling species found on both sides of the Atlantic Ocean. In the northwest Atlantic, they range from west Greenland to Cape Hatteras. *A. americanus* occurs in inshore waters from Hudson Bay and the Hudson Strait south to Virginia. In the Gulf of Maine, it is found at depths of 6-20 m (Scott and Scott, 1988; Robards et al., 1999). *A. dubius* occurs from Hudson Bay and Greenland south to the Scotian Shelf. It has a more offshore distribution than *A. americanus*, although the two species co-occur. Scott (1982) considered 73-90 m water depth to be the preferred depth range of *A. dubius*. The highest concentrations of sand lance on the Scotian Shelf have been found in depths less than 50 m at temperatures of 1-5°C. Historical surveys indicate a distribution pattern with concentrations over most of the offshore banks, including Georges Bank and Browns Bank (DFO, 1996a) (Figure 2-44). Both species live on sandy bottoms and burrow in the sand to rest and escape predators (Scott and Scott, 1988).

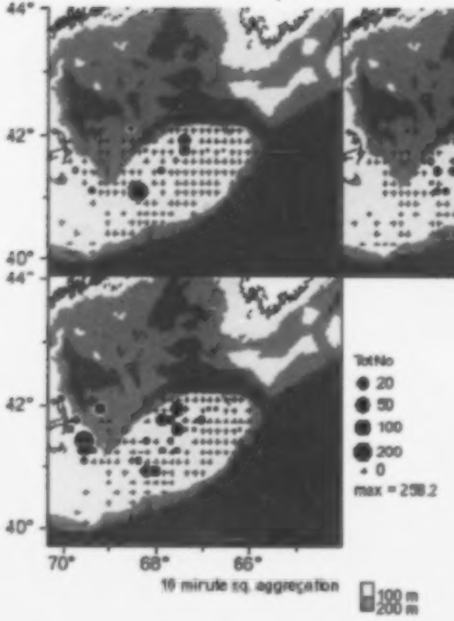


Figure 2-44. Distribution of sand lance caught in Georges Bank Research Survey from 1995-2009.

Sand lance is considered a planktonic feeder (DFO, 1996a). Larvae hatch prior to the spring bloom and feed on phytoplankton, diatoms, and dinoflagellates. On Georges Bank and in the Gulf of Maine region, copepods (mainly *Calanus finmarchicus*) are their primary food source, with euphausiids and polychaete larvae also comprising a significant portion of the diet (DFO, 1996a). In addition, mysids, cumaceans, amphipods, snails, small clams, isopods, and small crabs also contribute to the diet of sand lance (Scott and Scott, 1988). At night sand lance move up into the water to feed, commonly forming dense schools. They return to the bottom during the day to avoid predators (DFO, 1996a). Their annual recruitment is highly variable. Peaks in abundance were evident in the early-1970s and late-1980s to early-1990s (DFO, 1996a). In NAFO Divisions 4VWX, sand lance biomass has followed a declining trend since 2000, but remains above average for the series in 2008 (Clarke and Emberley, 2009) (Figure 2-45).

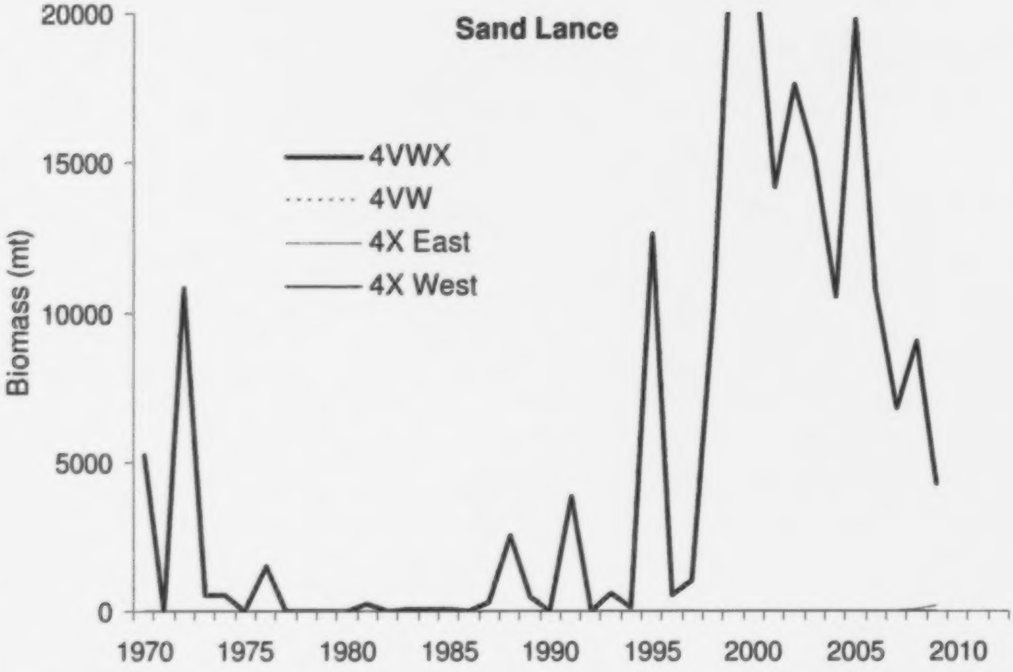


Figure 2-45. Biomass estimate for northern sand lance from the summer RV survey.

Population Structure Relative to Moratorium Area

The stock structure of sand lance is unknown and compounded by two species that co-occur and whose taxonomic separation is poorly resolved. There is no evidence of long-distance migration and they are, as a result, considered a relatively non-migratory species.

Life History, Location, and Timing

Sand lances in the northwest Atlantic have longevity of approximately 9 years and mature towards the end of their second year. Sand lances have a well defined breeding season, starting in November, ending before March, and peaking between December and January. They spawn on sand in shallow water during the winter months with eggs considered to be demersal and adhesive, adhering to sand and gravel on the bottom (Scott and Scott, 1988). Larvae have been concentrated on Sable Island Bank and Middle Bank, indicating that these are likely major spawning areas (DFO, 1996a). Larvae ascend to surface waters where they remain until they are 35 mm in length, at which time they descend to the bottom (Scott and Scott, 1988).

Known Vulnerabilities

Sand lance burrows into sandy bottoms and have demersal and adhesive eggs. As such they are vulnerable to any activities that interact with, disturb, or contaminate the bottom substrate. Sand lance is an important part of the marine food web, as it is a food source for marine mammals and groundfish species including cod, haddock, and pollock. Any impact on behavior may not only affect sand lance, but also other species that depend on them for forage.

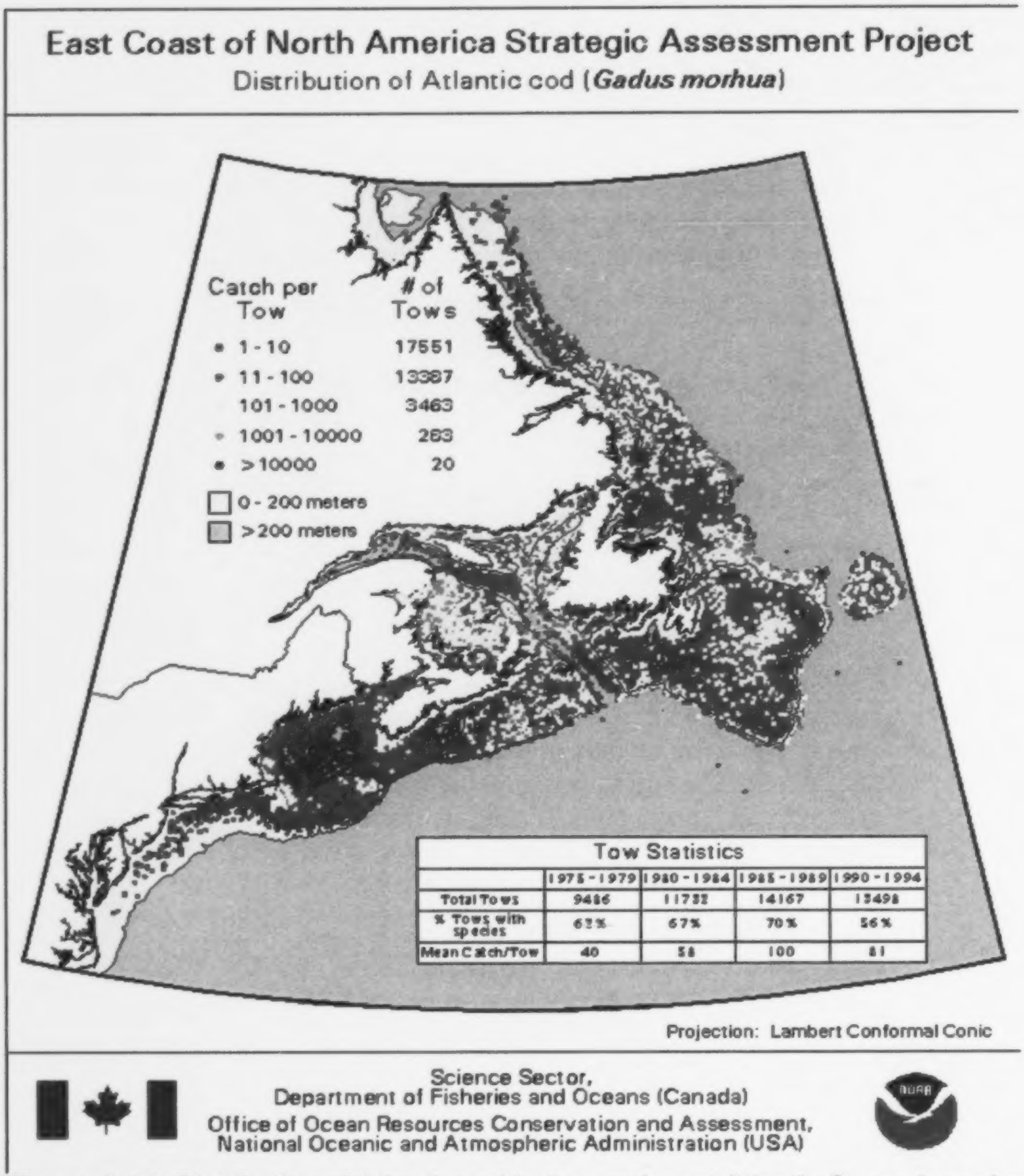
Status Designation

Sand lance is not listed pursuant to SARA and has not been evaluated by COSEWIC.

2.8.4 Atlantic Cod

Distribution, Habitat, Abundance, and Predator and Prey

Atlantic cod, *Gadus morhua*, is a demersal gadoid fish species that is found in the northwest Atlantic Ocean from Greenland to Cape Hatteras (Figure 2-46). Cod on Georges Bank is the most southerly cod stock in the world (Wise, 1958). Cod occur on rocky and pebbly grounds, gravel, sand, and a particularly gritty type of clay with broken shells. They are typical groundfish, usually found within 2 m or so of the bottom. Large cod remain closer to the bottom than smaller cod (Klein-MacPhee, 2002). They move in schools from deeper to shallower waters in seasonal cycles thought to be triggered by temperature, food, and spawning behavior. The gravel pavement of the Northeast Peak, which covers an underlying sandy deposit, is an important nursery ground for juvenile cod and is habitat that provides an important food source for demersal fish.


East Coast of North America Strategic Assessment Project
Distribution of Atlantic cod (*Gadus morhua*)
Catch per Tow
# of Tows
● 1 - 10 17551
● 11 - 100 13387
101 - 1000 3463
● 1001 - 10000 263
● >10000 20
☐ 0 - 200 meters
▨ >200 meters
Projection: Lambert Conformal Conic
Science Sector,
Department of Fisheries and Oceans (Canada)
Office of Ocean Resources Conservation and Assessment,
National Oceanic and Atmospheric Administration (USA)
NOAA

Tow Statistics

	1975 - 1979	1980 - 1984	1985 - 1989	1990 - 1994
Total Tows	9486	11732	14167	13498
% Tows with species	62%	67%	70%	56%
Mean Catch/Tow	40	58	100	81

Figure 2-46. Distribution of Atlantic cod in the northwest Atlantic Ocean based on research trawl surveys conducted by DFO and the U.S. National Oceanic and Atmospheric Administration (NOAA) from 1975-1994 (Brown et al., 1996).

Eastern Georges Bank cod have a diet consisting of fish, crustaceans, and molluscs. Algae appear to be the first food of cod larvae. After yolk-sac absorption, small zooplankton is the preferred food. Cod larvae eat all life stages of several species of copepods along with lamellibranch larvae and phytoplankton (Klein-MacPhee, 2002). Early juveniles tend to consume pelagic invertebrates rather than benthic invertebrates, medium-sized cod consume benthic invertebrates and fish, and larger cod primarily consume fish. In general, cod are opportunistic feeders, although they prefer sand lance, Cancer crab, and herring (Lough, 2004).

Based on the 2009 assessment (two assessment model formulations 'split M 0.2' and 'split M 0.5' have been used), the adult population biomass (ages 3+) of eastern Georges Bank cod declined from approximately 50,000 t in 1990 to less than 10,000 t in 1995. They fluctuated between 6000-13,000 t before decreasing in 2005 to somewhere in the range of 3800 t-6000 t. At the beginning of 2009, the adult population biomass increased to somewhere in the range of 8700 t-12,000 t (Figure 2-47). Resource productivity is currently poor due to low recent recruitment and low weights-at-age (TRAC, 2009b).

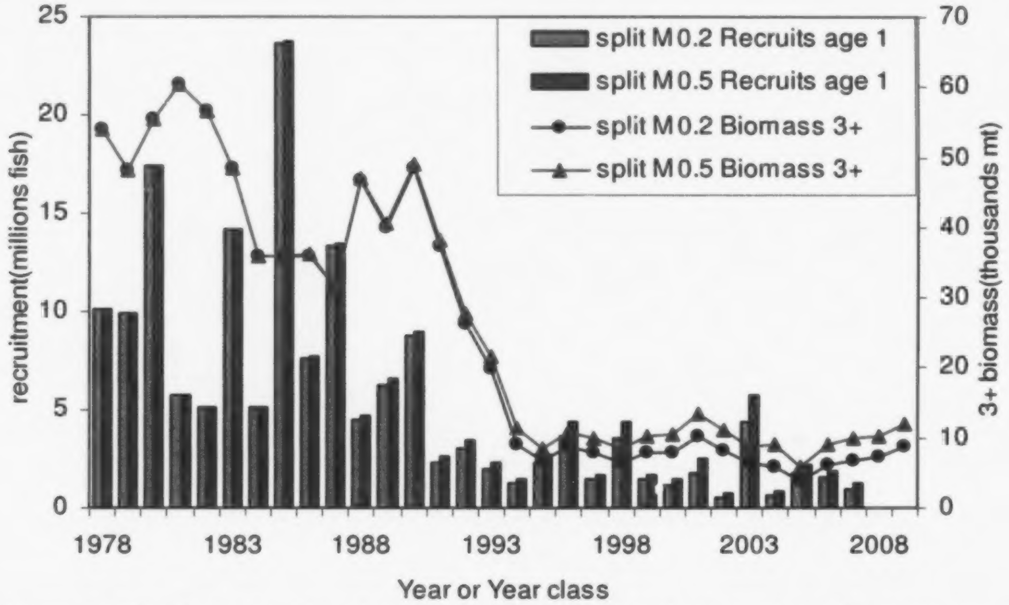


Figure 2-47. Biomass (lines) and recruitment (bars) of eastern Georges Bank cod.

Population Structure Relative to Moratorium Area

In the Gulf of Maine and Georges Bank region, the population structure of cod is complex, characterized by offshore sub-populations found on Georges Bank, Browns Bank, Great South Channel-Nantucket shoals, and localized coastal sub-populations that have limited connection to the offshore banks (Figure 2-48). The cod stock structure found on Georges Bank and adjacent areas is also complex, involving seasonal migration patterns and mixing grounds that facilitate exchange between putative stocks. In general, a resident spawning population of cod occupies eastern Georges Bank (Figure 2-49), with the exchange of cod between Georges Bank and Browns Bank being much stronger than between Georges Bank and the Great South Channel-Nantucket Shoal (Wang et al., 2009). Based on research survey result, most of the cod on eastern Georges Bank concentrate on the northeastern part.

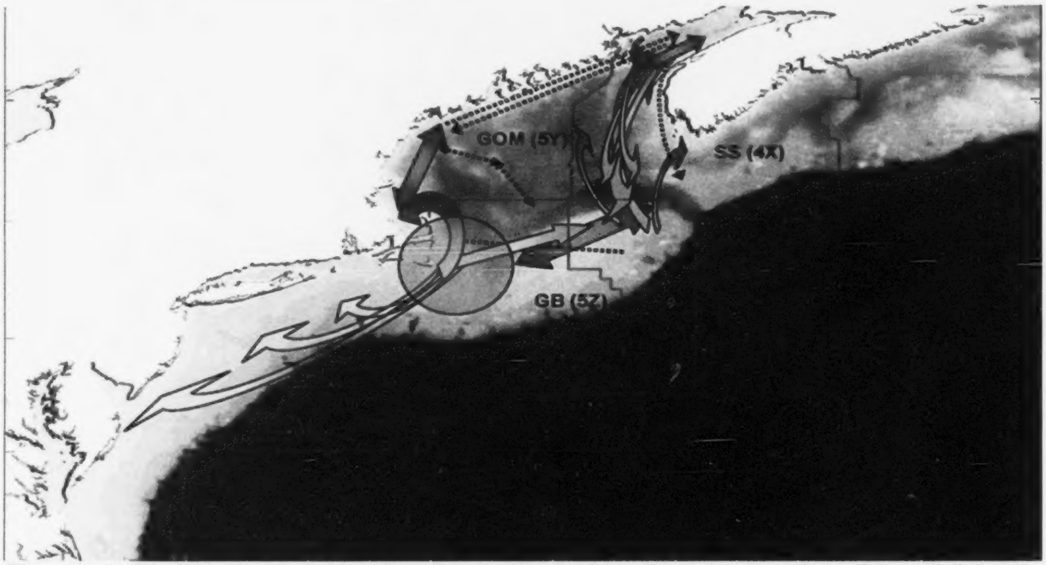

GOM (5Y)
SS (4X)
GB (5Z)

Figure 2-48. Movement corridors as indicated by the raw tagging data of Atlantic cod from the Northeast Regional Cod Tagging Program for the period 2003-2008 (O'Brien and Worcester, 2009). Note the arrows only show the direction of fish movement and are not quantitative indicators.

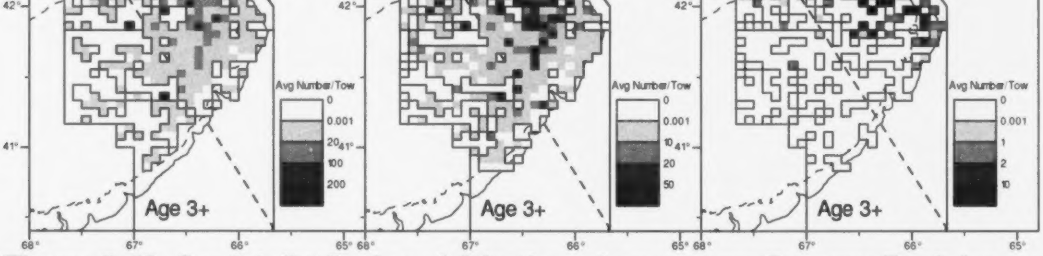

42°
41°
Avg Number/Tow
0
0.001
20
100
200
Age 3+
42°
41°
Avg Number/Tow
0
0.001
10
20
50
Age 3+
42°
41°
Avg Number/Tow
0
0.001
1
2
10
Age 3+
68°
67°
66°
65°
68°
67°
66°
65°
68°
67°
66°
65°

Figure 2-49. Spatial distribution of Atlantic cod on eastern Georges Bank from a 10 year average of 1999-2008 DFO survey data (left), NOAA spring survey (middle), and NOAA fall survey (right).

Life History, Location, and Timing

The most intense spawning activity of eastern Georges Bank cod occurs on the Northeast Peak of the Bank from February to March (Figure 2-50). Spawning occurs over the remainder of the Bank from October to May (Page et al., 1998; Page et al., 2001). Eggs are pelagic and drift for 2-3 weeks before hatching. The larvae are also pelagic until they reach 4-6 cm in size in approximately 3 months, after which they descend to the bottom (Lough, 2004). Cod eggs and larvae have been noted to drift 2-7 km per day in the gyre on Georges Bank (Lough et al., 1989). By the end of the first year, juvenile cod reach a mean length of 26 cm (Penttila and Gifford, 1976).

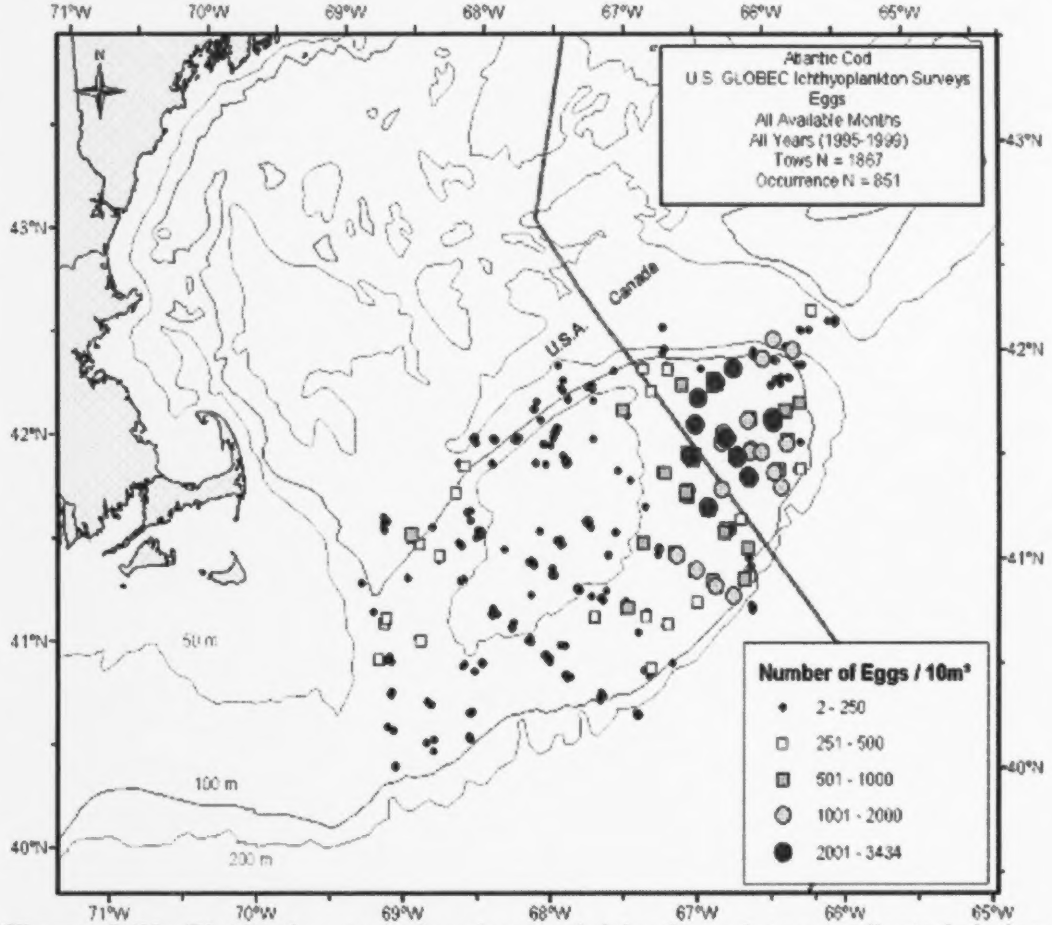

71°W
70°W
69°W
68°W
67°W
66°W
65°W
43°N
42°N
41°N
40°N
N
Atlantic Cod
U.S. GLOBEC Ichthyoplankton Surveys
Eggs
All Available Months
All Years (1995-1999)
Tows N = 1867
Occurrance N = 851
Canada
U.S.A.
50 m
100 m
200 m
Number of Eggs / 10m³
2 - 250
251 - 500
501 - 1000
1001 - 2000
2001 - 3434

Figure 2-50. Distribution and abundance of Atlantic cod eggs collected during GLOBEC Georges Bank ichthyoplankton surveys for all available years (February-July, 1995, and January-June, 1996-1999) (Lough, 2004).

Known Vulnerabilities

Cod have a swim bladder that is vulnerable to extreme changes in pressure. Both sexes of cod can produce sound with drumming muscles surrounding their swim bladders (Finstad and Nordeide, 2004) and cod have been observed to vocalize during reproductive activity (Fudge and Rose, 2009) in the range of approximately 30-250 Hz (Nordeide and Kjellsby, 1999). Studies have shown that cod have elaborate courtship behaviour (Brawn, 1961; Rowe and Hutchings, 2006).

Status Designation

Cod on eastern Georges Bank is co-managed by Canada and the U.S., since it is a transboundary resource. With the decline of fish population abundance and lower total allowable catch (TAC) since mid-1990s, most of the fish have been captured as bycatch from commercial fisheries on the northeast part of Georges Bank (Figure 2-51). Atlantic cod is not listed pursuant to SARA. The southern Canada designable unit of Atlantic cod, which includes eastern Georges Bank cod, was assessed as ‘endangered’ by COSEWIC in April 2010.

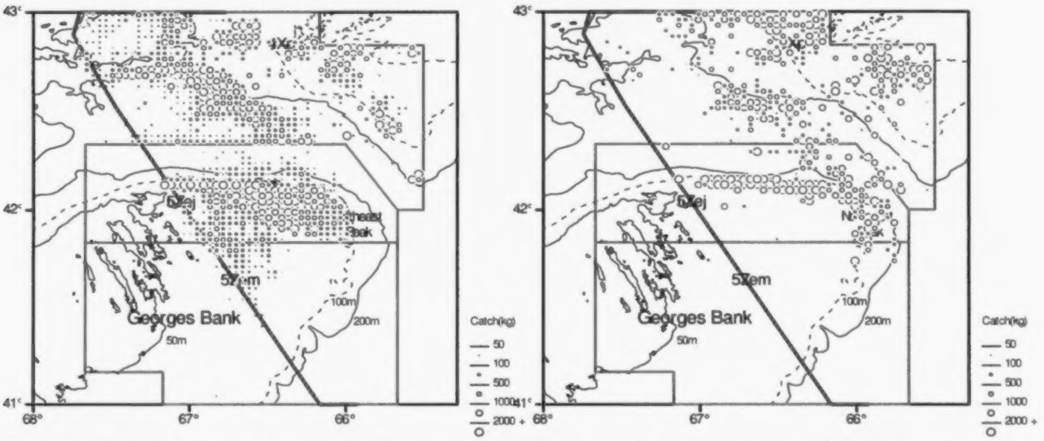
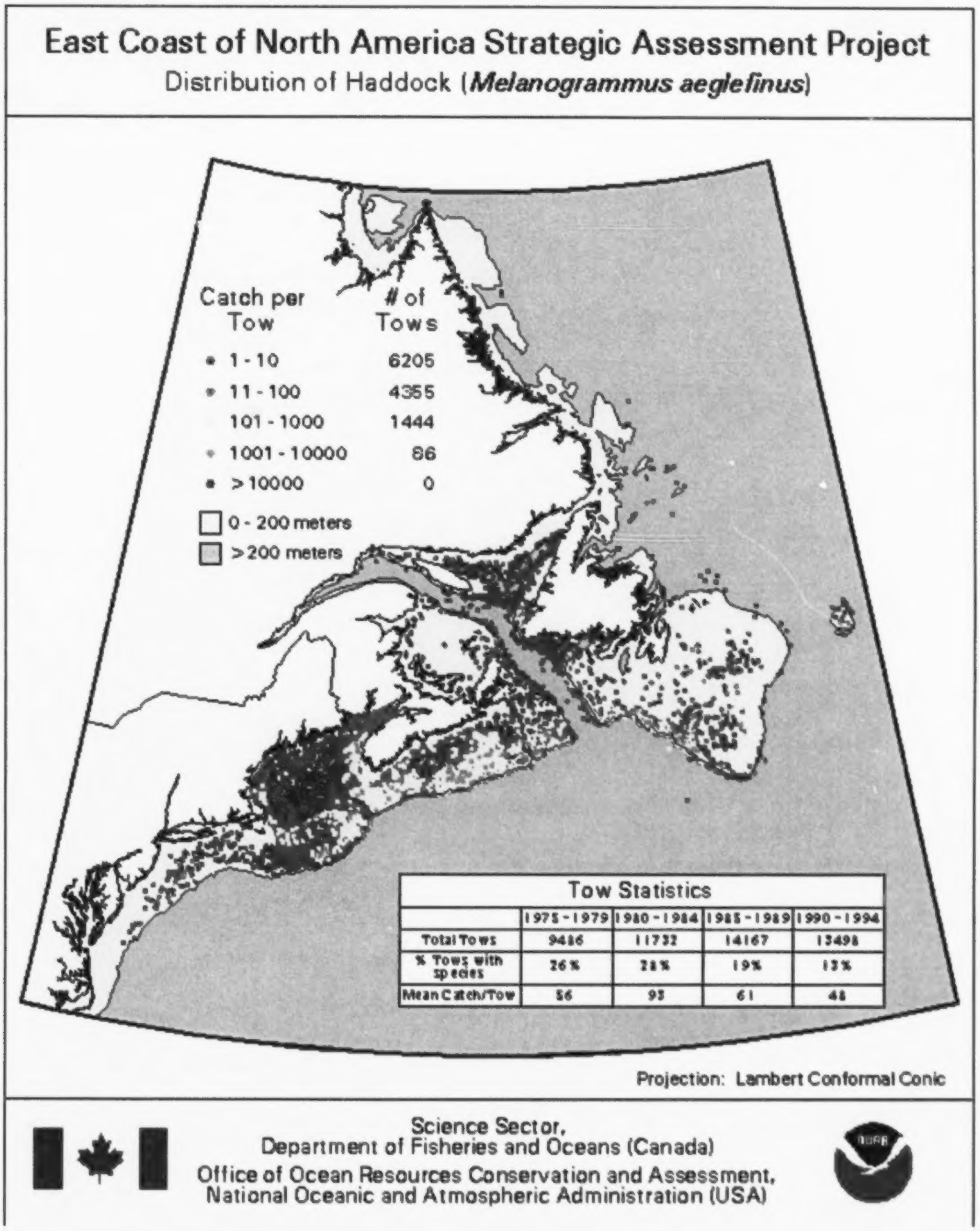


Figure 2-51. Fishing distribution of Atlantic cod on eastern Georges Bank in 2008 from bottom trawl (left) and longline (right) fisheries.

2.8.5 Haddock

Distribution, Habitat, Abundance, and Predator and Prey

Haddock, *Melanogrammus aeglefinus,* is a bottom dwelling gadoid fish species. It is found on both sides of the North Atlantic Ocean. In the western Atlantic Ocean, haddock can be found from Greenland to Cape Hatteras (Figure 2-52). Adults range in size from 30 cm - 1 m in length and can live for more than 16 years. A major spawning concentration of haddock resides on eastern Georges Bank. Eastern Georges Bank haddock are typically found on the Bank at water depths of 45-240 m. Haddock generally live in deeper waters than cod and are most common at temperatures of 2-10 °C. Adult haddock appear relatively sedentary, although seasonal migrations occur during periods of spawning activity. Haddock are more closely associated with the bottom than cod, preferring broken ground, gravel, pebbles, clay, smooth hard sand, sticky sand of gritty consistency, and where there are broken shells (Klein-MacPhee 2002).


East Coast of North America Strategic Assessment Project
Distribution of Haddock (*Melanogrammus aeglefinus*)
Catch per Tow
# of Tows
● 1 - 10 6205
● 11 - 100 4355
101 - 1000 1444
● 1001 - 10000 86
● >10000 0
☐ 0 - 200 meters
▨ >200 meters
Projection: Lambert Conformal Conic
Science Sector,
Department of Fisheries and Oceans (Canada)
Office of Ocean Resources Conservation and Assessment,
National Oceanic and Atmospheric Administration (USA)
NOAA

Tow Statistics

	1975 - 1979	1980 - 1984	1985 - 1989	1990 - 1994
Total Tows	9486	11732	14167	13498
% Tows with species	26%	28%	19%	13%
Mean Catch/Tow	56	93	61	48

Figure 2-52. Distribution of haddock in the northwest Atlantic Ocean based on research trawl surveys conducted by DFO and NOAA from 1975-1994 (Brown et al., 1996).

Pelagic larvae and small juveniles feed on phytoplankton, copepods, and invertebrate eggs in the upper part of the water column. Juveniles eat small crustaceans, primarily copepods and euphausiids, as well as polychaetes, and small fishes. The diet changes to primarily benthic prey when they assume a demersal existence between 3-5 months of age. Demersal haddock feed primarily on small benthic invertebrates, such as crustaceans, mollusks, echinoderms, and worms, as well as some fishes. The diet becomes more varied as they increase in size.

Eastern Georges Bank haddock adult biomass (ages 3+) increased from 9100 t in 1993 to 81,800 t in 2003, declined to 57,800 t in 2005, and subsequently tripled to a record-high 155,600 t in 2009 due primarily to the exceptional 2003 year-class (Figure 2-53). With expanded age structure, broad spatial distribution, and improved recruitment, current resource productivity is high, hindered only by recent reductions in fish weights at age (TRAC, 2009c).

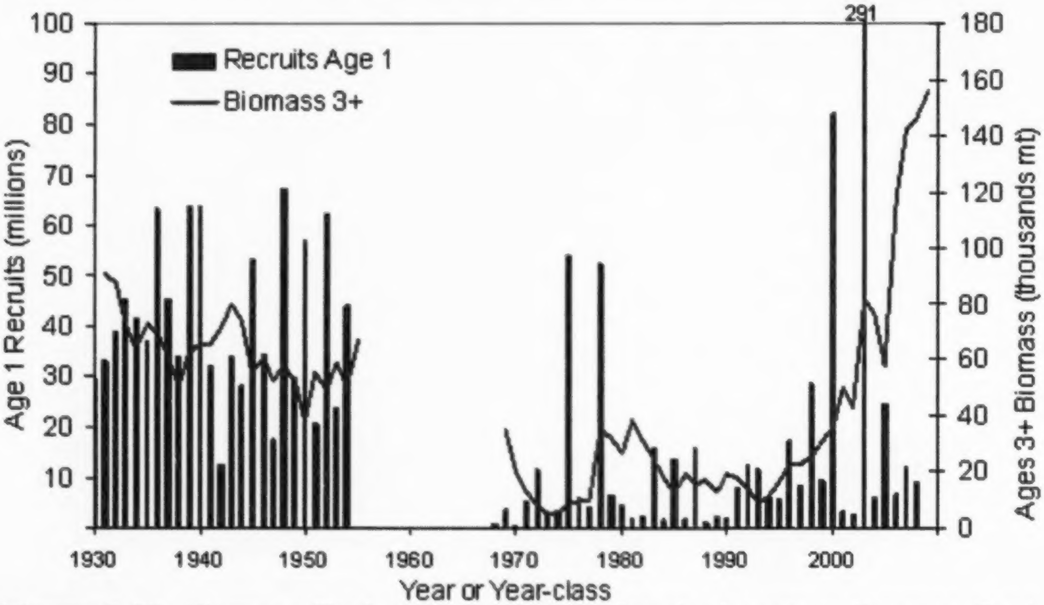


Figure 2-53. Biomass (line) and recruitment (bars) of eastern Georges Bank haddock.

Population Structure Relative to Moratorium Area

Studies have shown a net southwest migration of haddock towards shallower water depths of the central eastern Georges Bank plateau during winter to prepare for spring-time spawning, and a net northeast migration towards deeper slopes where they reside during the summer and fall (Van Eeckhaute et al., 1999) when shallower water temperatures are too warm. Age 0 haddock are widely dispersed over the eastern Georges Bank area in fall but, by spring, are more concentrated on the northeast peak and southern flank at age 1 (Figure 2-54). In spring, haddock at ages 3 and older are broadly distributed between shallower waters of central Georges Bank towards the Northeast Peak and northern edge of the Bank. This is the primary spawning area for eastern Georges Bank haddock. Adult haddock spread further west during March to April and are found throughout the eastern Georges Bank area at that time. In February, they are more aggregated on the northern part of the Bank and an area of concentration near the middle of the bank is also observed. Age 2 haddock show a similar distribution to the adults.

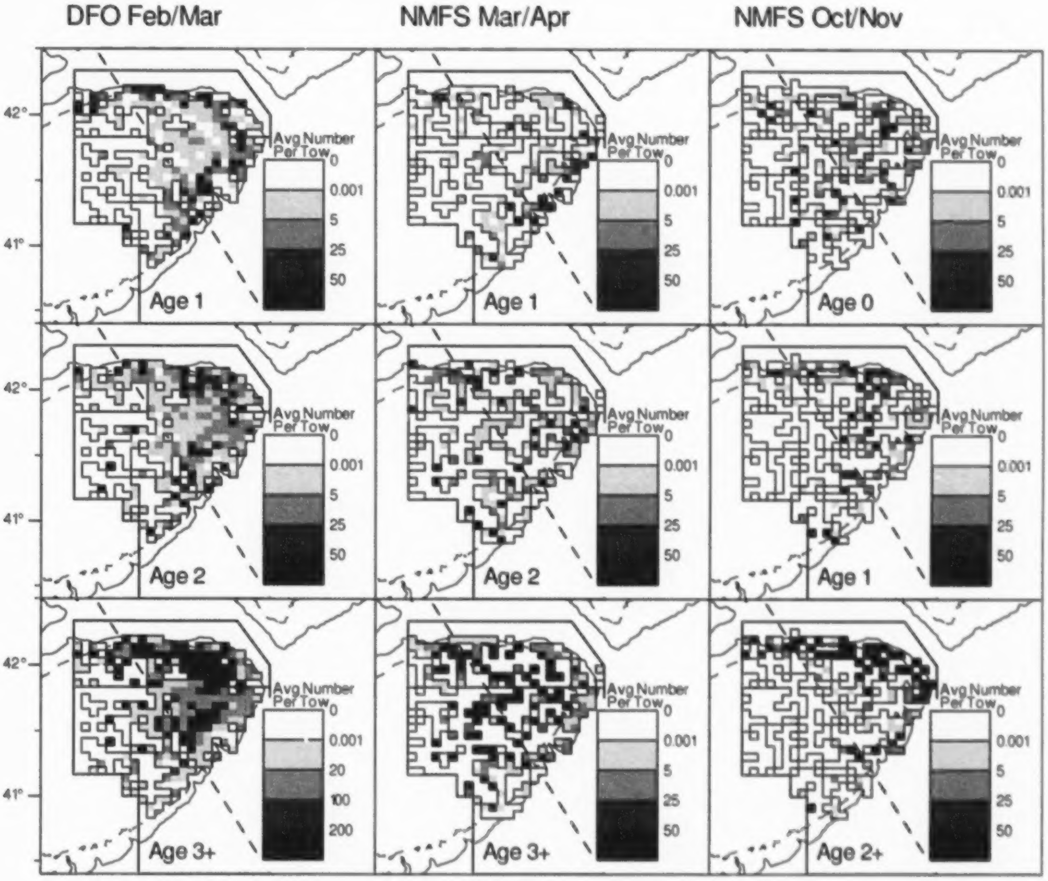


Figure 2-54. Average distribution of haddock by age group from 1999-2008 in the eastern Georges Bank management area as observed from the DFO February/ March survey and the NOAA March/April and October/November surveys.

Life History, Location, and Timing

Haddock are broadcast spawners that spawn batches of eggs over a time span of several weeks. Females produce from 12,000-3,000,000 eggs per fish. Haddock eggs are buoyant and are concentrated in the upper part of the water column. Incubation times vary with temperature and, at water temperatures typically found on Georges Bank, eggs hatch in about 15 days, although this can range from 6 to 42 days at extreme temperature. The larval period is roughly 30-42 days. Juveniles remain in the upper part of the water column for 3-5 months, after which they settle on the bottom when suitable habitat is found (Brodziak, 2005). Larvae and pelagic juveniles are concentrated in a limited depth stratum defined by the thermocline, which is usually between 10-40 m (Klein-MacPhee, 2002). The prey organisms are concentrated above the thermocline, providing an abundant food source. Small haddock (i.e. 60-70 mm in length) have been found to associate with jellyfish, which results in their movement being controlled in part by the drift of jellyfish.

Surveys of haddock eggs, which occur at stage 3 or later, allow for a differentiation with cod eggs, and provide the spatial extent of the spawning area. The majority of spawning activity occurs between early- to mid-March and mid- to late-April (Page et al., 1998), but eggs were found from January to July as observed by MARMAP (Figure 2-55) and GLOBEC (Figure 2-56). Haddock egg distributions indicate the presence of eggs throughout most of the fishery statistical units on Georges Bank in water depths less than 100 m. Presence of haddock eggs, however, are most prevalent on the eastern portion of the Bank (Figure 2-56). As larvae develop, they are re-distributed between the Northeast Peak and southern edge of the Bank, consistent with mean circulation patterns in the region (Van Eeckhaute et al., 1999).

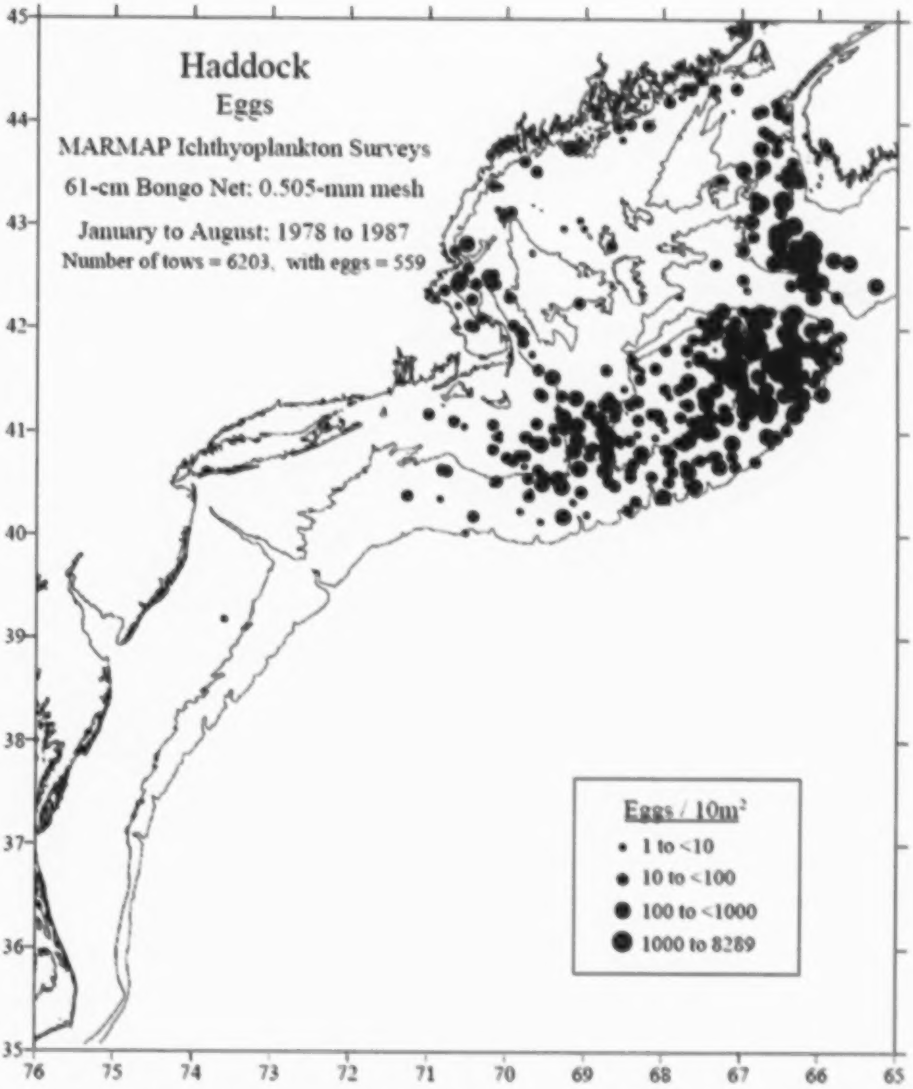

Haddock
Eggs
MARMAP Ichthyoplankton Surveys
61-cm Bongo Net: 0.505-mm mesh
January to August: 1978 to 1987
Number of tows = 6203, with eggs = 559
Eggs / 10m²
1 to <10
10 to <100
100 to <1000
1000 to 8289
45
44
43
42
41
40
39
38
37
36
35
76
75
74
73
72
71
70
69
68
67
66
65

Figure 2-55. Distribution and abundance of haddock eggs (aggregated from 1978-1987), as observed from NEFSC MARMAP ichthyoplankton surveys (Brodziak, 2005).

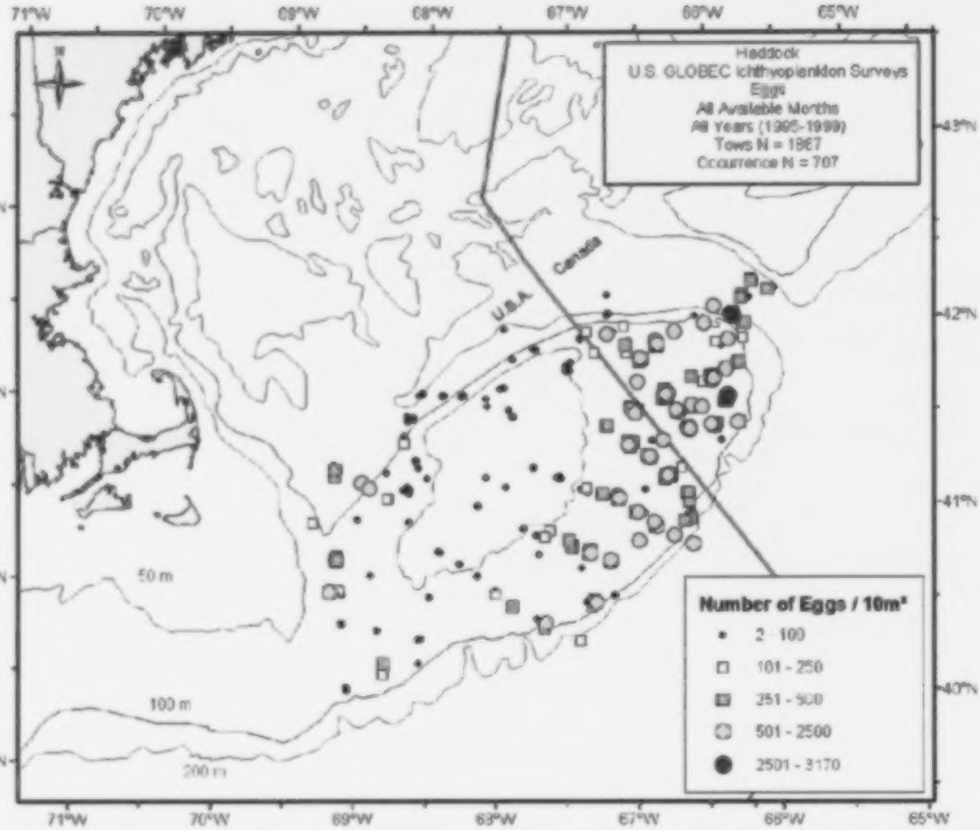

71°W
70°W
69°W
68°W
67°W
66°W
65°W
N
Haddock
U.S. GLOBEC Ichthyoplankton Surveys
Eggs
All Available Months
All Years (1995-1999)
Tows N = 1867
Occurrence N = 707
43°N
42°N
41°N
40°N
Canada
U.S.A.
50 m
100 m
200 m
Number of Eggs / 10m²
2 - 100
101 - 250
251 - 500
501 - 2500
2501 - 3170

Figure 2-56. Distribution and abundance of haddock eggs as observed from GLOBEC ichthyoplankton surveys, February to July, 1995, and January to June, 1996-1999, combined (Brodziak, 2005).

The GLOBEC program demonstrated that the highest numbers of larvae were in March and April and mostly in southern areas of the Bank between the 50-100 m isobaths. Haddock begin to settle to the bottom by about July and August. As they age to 2 years, they start concentrating on the northern edge and Northeast Peak. By age 2, they begin to display the seasonal migration associated with spawning, which is evident for adult haddock. Very large year-classes are widespread throughout the stock area, both as juveniles and adults, as was observed for the 1963 and, more recently, the 2003 year-class. Many haddock mature by age 2, although it is uncertain whether these fish spawn successfully. By age 3, eastern Georges Bank haddock are considered to be mature.

Known Vulnerabilities

Haddock have a swim bladder that is vulnerable to extreme changes in pressure. Both male and female haddock can produce a range of sounds (Hawkins et al., 1967; Hawkins and Rasmussen, 1978; Hawkins, 1986), and their sounds have been observed during spawning activity. Male haddock produce sounds that vary in their characteristics as courtship proceeds (Hawkins et al., 1967; Hawkins, 1986; Hawkins and Amorim, 2000). Since juvenile and adult haddock are closely associated with the bottom and their prey species are generally bottom dwellers, living in or on the substrate, any contamination of the substrate by pollutants has the potential to affect the haddock directly through exposure to the pollutants or indirectly by ingestion of prey items that have been exposed to pollutants. All life stages would be vulnerable to pollutants dispersed in the water column.

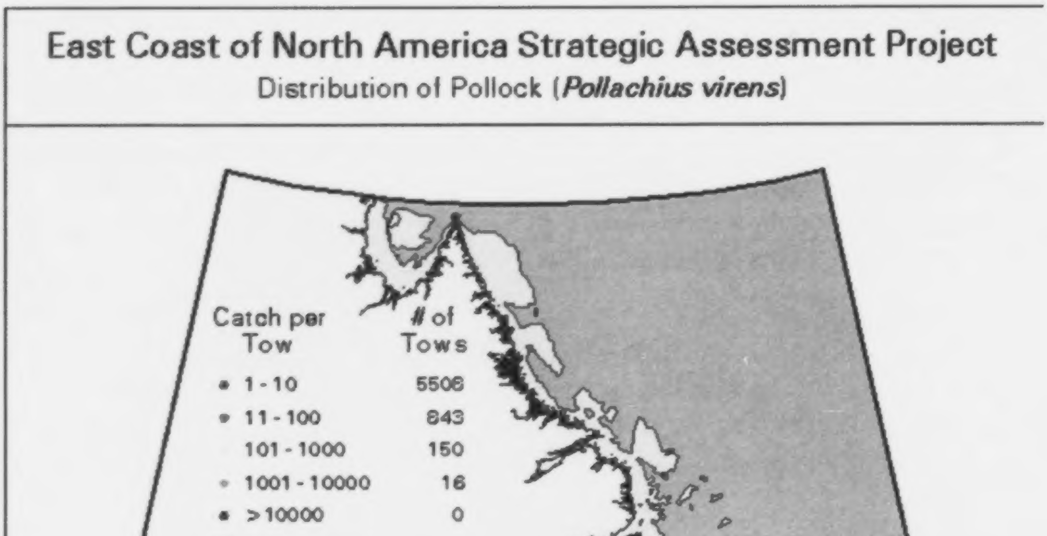
Status Designation

Eastern Georges Bank haddock is not listed pursuant to SARA and has not been evaluated by COSEWIC.

2.8.6 Pollock

Distribution, Habitat, Abundance, and Predator and Prey

Pollock, *Pollachius virens,* is a gadoid fish species that is found on both sides of the North Atlantic. In the western North Atlantic, it ranges from southern Labrador to Cape Hatteras, with major concentrations on Georges Bank, in the Gulf of Maine, and on the Scotian Shelf (Figure 2-57). Pollock are found at depths ranging from the surface to 380 m depth and at bottom temperatures varying from 5-8°C (Scott, 1982). Offshore pollock aggregations are often associated with hard bottom topographic features, such as rises, ridges, or mounts, but they are generally unselective of bottom type and can be associated with sediments ranging from gravel to clay (Scott, 1982).


East Coast of North America Strategic Assessment Project
Distribution of Pollock (*Pollachius virens*)
Catch per Tow
# of Tows
1 - 10
5508
11 - 100
843
101 - 1000
150
1001 - 10000
16
>10000
0
0 - 200 meters
>200 meters
Projection: Lambert Conformal Conic

Tow Statistics

	1975 - 1979	1980 - 1984	1985 - 1989	1990 - 1994
Total Tows	9486	11732	14167	13498
% Tows with species	13%	13%	11%	9%
Mean Catch/Tow	7	28	20	16

Figure 2-57. Distribution of pollock in the northwest Atlantic Ocean based on research trawl surveys conducted by DFO and NOAA from 1975-1994 (Brown et al., 1996).

Juvenile pollock feed on crustaceans, especially small euphausiids and amphipods, although small fishes including herring and sand lance are also consumed. Food of adult pollock includes euphausiids, squid, and fish such as herring, sand lance, and silver hake (DFO, 2009c). The diet of pollock from the Scotian Shelf and Bay of Fundy has shown decadal changes, with euphausiids (krill) being the predominant prey in the 1960s and 1980s, less so in the 1990s, but has been predominant again since 2003 (Carruthers et al., 2005).

Estimates of age 4+ (considered spawning stock) biomass declined from approximately 66,000 t in 1984 to approximately 7500 t in 2000. Biomass has been rebuilding since 2000, increasing steadily to about 29,000 t in 2007 then declining to 27,000 t in 2008 (Figure 2-58). Concerning recruitment, the 2001 year-class was estimated to be the strongest at age 2 since the 1988 year-class, and the third highest in the time series. Early indications for the 2004 and 2005 year-classes are that they are the lowest in the time series, while the 2002 and 2003 year-classes are about average. Over the past decade, pollock biomass has been recovering such that catches of pollock from the Canadian portion of Georges Bank have represented about 20% of total landings (average = 1100 t for 2000-2009) (Stone et al., 2009).

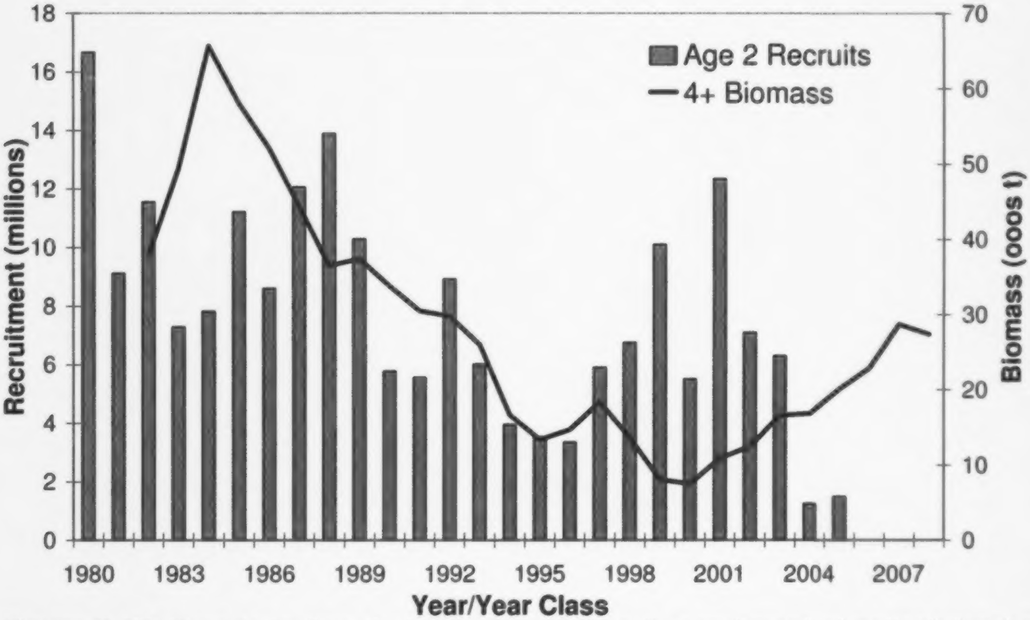


Figure 2-58. Trends in Age 4+ biomass and Age 2 recruitment of pollock for the Western Component population (DFO, 2009c).

Population Structure Relative to Moratorium Area

A detailed evaluation of stock structure in 2003 indicated that the current Maritimes management unit for pollock (NAFO Divisions 4VWX+5) is represented by two population components: a slower-growing Eastern Component (4VW+4Xmn) and a faster-growing Western Component (4Xopqrs+5) (Neilson et al., 2003). For management purposes, the southernmost limit of the Western Component is considered to include fish in the Canadian part of Georges Bank and the eastern Gulf of Maine. Tagging studies suggest considerable movement of pollock between the Scotian Shelf and Georges Bank, but less between the Scotian Shelf and Gulf of Maine (Mayo et al., 1989; Mayo, 1998). A recent evaluation of Canadian tagging data by Neilson et al. (2006)

demonstrated that pollock tagged and released in the Bay of Fundy were recaptured on northeastern Georges Bank and in the eastern Gulf of Maine, implying that they are capable of extensive movements. The migratory routes and degree of mixing among these areas have yet to be determined.

Life History, Location, and Timing

The life history of pollock involves an offshore spawning and larval phase, recruitment to the coastal environment for a period of one to two years, followed by an offshore migration. Unlike other cod-like fishes, pollock show strong schooling behaviour and spend more time moving freely through the water column rather than near the bottom. Spawning areas have been identified on the Scotian Shelf, northeastern Georges Bank, and in the western Gulf of Maine. Based on the seasonal distribution of pollock eggs and larvae from Canadian ichthyoplankton surveys, spawning occurs on northeastern Georges Bank during November-December (Neilson and Perley, 1996; Hanke et al., 2001). The U.S. MARMAP icththyoplankton surveys indicate that the highest egg and larval densities occur on the Bank from November through to February (Reid et al., 1999).

Known Vulnerabilities

Pollock produce sounds by means of a multi-lobed swim bladder vibrated by contractions of associated muscles, as well as general body contractions (Fish and Mowbray, 1970). Their hearing range is similar to that of cod, and they may be sensitive to excessive noise levels.

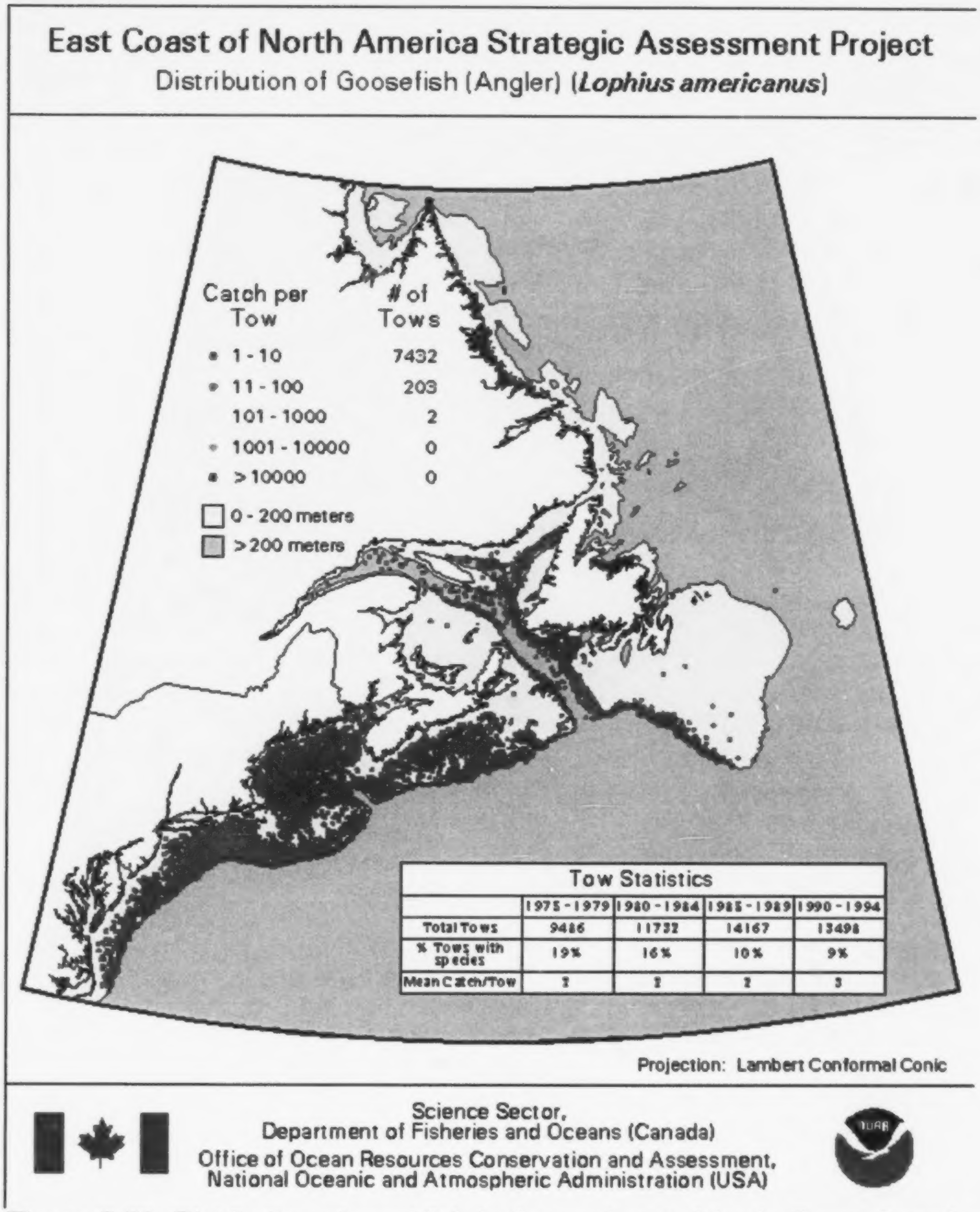
Status Designation

Pollock is not listed pursuant to SARA and has not been evaluated by COSEWIC.

2.8.7 Monkfish

Distribution, Habitat, Abundance, and Predator and Prey

Monkfish, *Lophius americanus*, also called goosefish or angler, are distributed from the Grand Banks and Northern Gulf of St. Lawrence south to Cape Hatteras (Figure 2-59). Monkfish are a bottom dwelling species typically found on sand, mud, and shell habitats. Individuals have been collected from inshore areas to depths greater than 800 m, although highest concentrations occur from 70-100 m water depth and in deeper waters of greater than 190 m depth. They have been found at temperatures from 0-24°C but, in Canadian waters, appear most abundant at water temperatures of 3-9°C (DFO, 2002a). Monkfish make seasonal onshore-offshore migrations in response to thermal conditions and prey availability. In the Gulf of Maine, monkfish move and stay offshore to avoid cold coastal conditions in the winter-spring and return inshore as coastal waters warm in the summer and fall (Steimle et al., 1999).


East Coast of North America Strategic Assessment Project
Distribution of Goosefish (Angler) (*Lophius americanus*)
Catch per Tow
# of Tows
● 1 - 10 7432
● 11 - 100 203
101 - 1000 2
● 1001 - 10000 0
● >10000 0
☐ 0 - 200 meters
▨ >200 meters
Projection: Lambert Conformal Conic
Science Sector,
Department of Fisheries and Oceans (Canada)
Office of Ocean Resources Conservation and Assessment,
National Oceanic and Atmospheric Administration (USA)
NOAA

Tow Statistics

	1975 - 1979	1980 - 1984	1985 - 1989	1990 - 1994
Total Tows	9486	11732	14167	13498
% Tows with species	19%	16%	10%	9%
Mean Catch/Tow	2	2	2	3

Figure 2-59. Distribution of monkfish in the northwest Atlantic Ocean based on research trawl surveys conducted by DFO and NOAA from 1975-1994 (Brown et al., 1996).

Larvae feed on zooplankton, including copepods, crustacean larvae, and chaetognaths. Small juveniles start eating fish, such as sand lance, soon after they settle to the bottom, but invertebrates, especially crustaceans, can make up a large part of the diet. The consumption of invertebrates decreases among larger juveniles. Diets can vary regionally and seasonally depending on what prey is available. Monkfish are opportunistic feeders. The diet of an adult consists primarily of fish, crustaceans, and squid. On occasion, however, they have been known to eat sea birds and diving ducks (Steimle et al., 1999; Johnson et al., 2008).

Based on a 2002 assessment, abundance of adult monkfish in 4X remained at or below the average (approximately 500,000 individuals). The proportion of large fish, greater than 60 cm in length, continued to decline and biomass remained low. There was evidence of improved immature abundance since 1992, particularly in 1995 and 2000. This, however, did not appear to result in increased biomass (DFO, 2002a). Biomass had shown some increase, but to a lesser degree than abundance, and remained at a low level of approximately 3000 t. Though there is no evidence to suggest a north to south migration pattern, U.S. survey indices in the Gulf of Maine were similar to those on the Scotian Shelf (Beanslands et al., 2000).

Population Structure Relative to Moratorium Area

The stock structure of monkfish is unknown, but U.S. survey distributions suggest northern (i.e. Gulf of Maine and northern Georges Bank) and southern (i.e. southern Georges Bank and Mid-Atlantic Bight) components with shallow waters of Georges Bank as a boundary zone. Canadian survey distributions do not suggest a discontinuity between Scotian Shelf and Georges Bank components of the stock. While onshore-offshore migrations have been reported (Richards et al., 2008), the degree of mixing in both U.S. and Canadian waters remains unknown and large scale migrations have not been reported (DFO, 2002a).

Life History, Location, and Timing

Females appear to grow larger and live longer than males. Females live up to 12 years of age, reaching a size of over 1 m in length, while males have not been found older than 9 years of age and at approximately 90 cm in length. Sexual maturity occurs between ages 3 and 4. Spawning occurs from spring through early fall with a peak in May to June. Females lay a non-adhesive, buoyant mucoid veil, although the method of fertilization has not been observed or reported. Eggs hatch in 7-22 days, after which the larvae spend several months in a pelagic phase before settling to the bottom at a size of about 8 cm in length (DFO, 2002a). Spawning locations are not known but are thought to be on inshore shoals to offshore, as egg veils have been found close to shore and in deep water (Richards et al., 2008).

Known Vulnerabilities

Vulnerabilities for monkfish are not known, but are expected to be similar to other demersal fish with buoyant eggs and pelagic larvae.

Status Designation

Monkfish is not listed pursuant to SARA and has not been evaluated by COSEWIC.

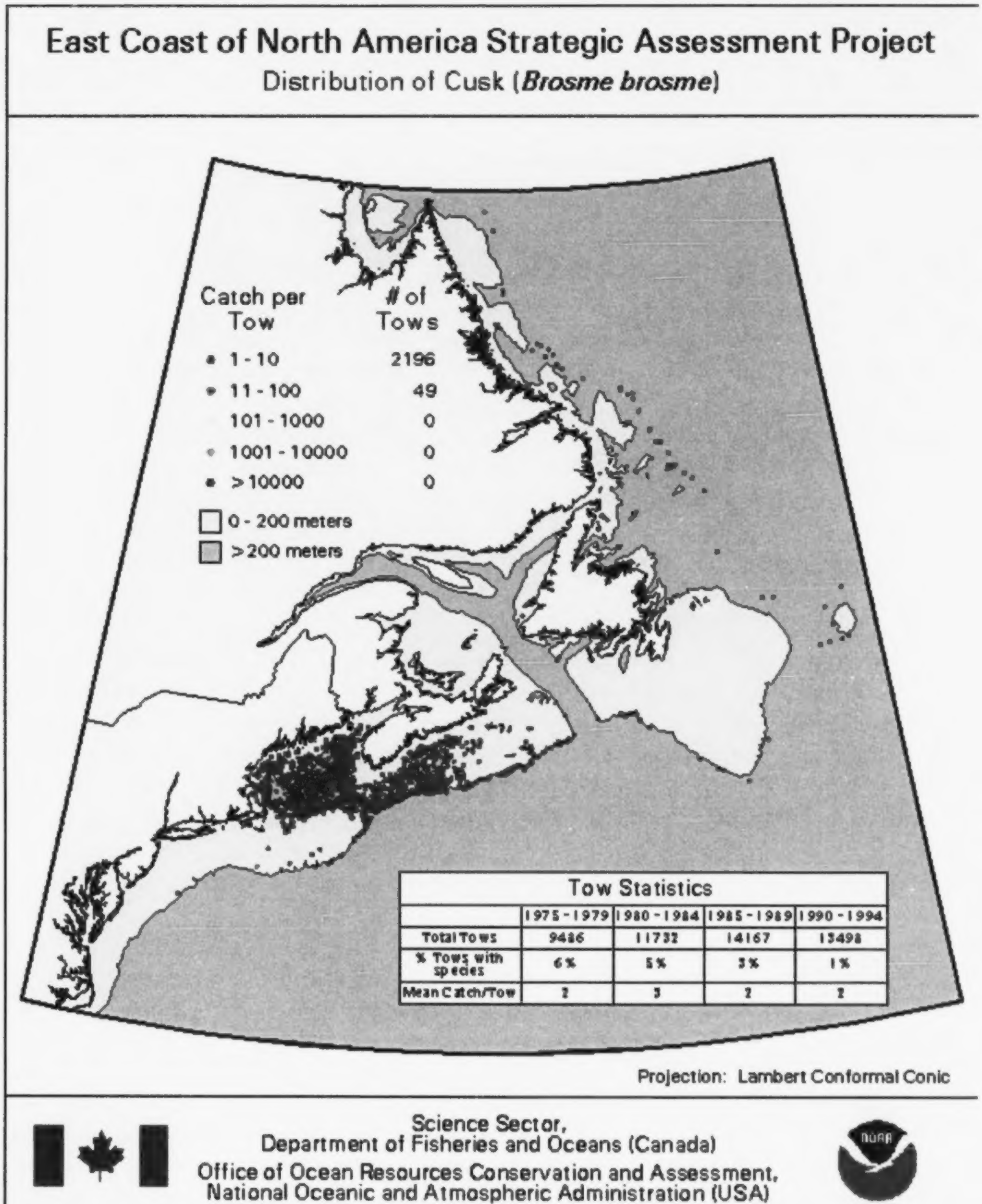
2.8.8 Cusk

Distribution, Habitat, Abundance, and Predator and Prey

Cusk, *Brosme brosme*, is a solitary, sedentary, slow swimming fish species. It is distributed across the northern North Atlantic from the United States, north to Greenland, across to Iceland, Svalbard, along the Murmansk Coast, and south in the Northeast Atlantic to Ireland. It has also been found along the mid-Atlantic Ridge (Figure 2-60). In Canadian waters, cusk is most common in the Gulf of Maine, western Scotian Shelf, and along the edge of the Scotian Shelf to Banquereau Bank. It is rare in the Gulf of St. Lawrence and the inner Bay of Fundy (Harris and Hanke, 2010).

Adult cusk prefer a hard, rocky bottom habitat, including boulders, rocks, or pebbles (Oldham, 1972). Cusk is considered a deep-water species, although it has been observed, less commonly, in shallow waters. They prefer relatively warm intermediate depths and are found at temperature from 2-12°C on the Scotian Shelf and 1-10°C in the Gulf of Maine (Scott and Scott, 1988). Globally, their depth range is reported to be from 20-1185 m, but are rarely found deeper than 400 m (Oldham, 1966; Hareide and Garnes, 2001). In the Canadian Atlantic, cusk are reported to occur between 150-450 m, however, Harris and Hanke (2010) observed the highest catch rates between 400-600 m with cusk caught at depths as great as 1185 m.

The diet of cusk in the northwest Atlantic is not well known, as their stomachs generally evert when they are brought to the surface. Limited stomach samples, however, have contained invertebrates, crabs, and shrimps. A variety of fish species have also been found in cusk stomachs. On occasion, cusk have been found in the diets of cod and halibut (Harris et al., 2002). Cusk abundance has declined since the 1970s, although there is insufficient data to determine the degree of decline and there is conflicting evidence on whether cusk abundance has continued to decline since the late 1990s (DFO, 2008c). Based on halibut Industry survey data, this decline has stabilized (Harris and Hanke, 2010). It is unlikely that the conflicting evidence will be resolved in the near future. A by-catch cap of 1000 t for NAFO Divisions 4VWX was first implemented in 1999 (Figure 2-61). In 2003, this cap was reduced to 750 t for 4VWX+5 where it has since remained. The effectiveness of this measure for mitigation is unknown since the exploitation rate is unknown. The ability to detect future trends in abundance is limited by current monitoring programs (DFO, 2008c).


East Coast of North America Strategic Assessment Project
Distribution of Cusk (*Brosme brosme*)
Catch per Tow
# of Tows
• 1 - 10 2196
• 11 - 100 49
101 - 1000 0
• 1001 - 10000 0
• >10000 0
☐ 0 - 200 meters
▨ >200 meters
Projection: Lambert Conformal Conic
Science Sector,
Department of Fisheries and Oceans (Canada)
Office of Ocean Resources Conservation and Assessment,
National Oceanic and Atmospheric Administration (USA)
NOAA

Tow Statistics				
	1975 - 1979	1980 - 1984	1985 - 1989	1990 - 1994
Total Tows	9486	11732	14167	13498
% Tows with species	6%	5%	3%	1%
Mean Catch/Tow	2	3	2	2

Figure 2-60. Distribution and abundance of cusk in the northwest Atlantic Ocean based on research trawl surveys conducted by DFO and the U.S. National Marine Fisheries Service (NMFS) from 1975-1994 (Brown et al., 1996).

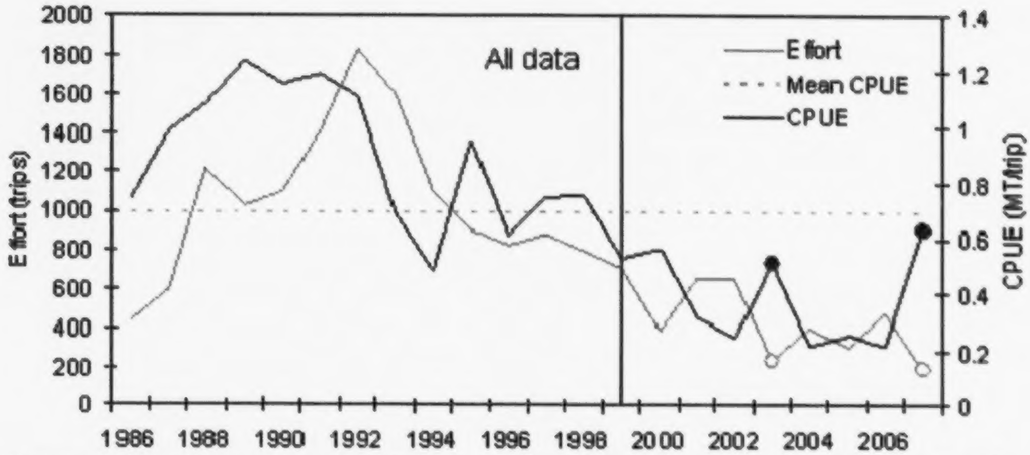


Figure 2-61. Catch per unit effort (t trip^{-1}) of cusk by quota year in the longline fishery in 4Xnopqu, captured by vessels in tonnage classes 2 and 3. The dashed line represents the long-term mean. Due to cusk closures to longliners, 2003 is only represented by April-November and 2007 is only represented from April-September (indicated by dots). A bycatch cap of 1000 t for longliners in 4VWX was first implemented in 1999 (indicated by vertical line). It reduced to 750 t for longliners in 4VWX+5 in 2003 where it continues to remain.

Population Structure Relative to Moratorium Area

Cusk are thought to be sedentary. At present, there is no evidence to suggest that there are distinct populations of cusk in Atlantic Canada (DFO, 2008c). Around Georges Bank, the areas of highest catches are in the deeper waters in the Northeast Channel and off the Northeast Peak, as well as in the Fundian Channel. Catches on Georges Bank itself are lower, but do occur (Harris and Hanke, 2010). Cusk on banks are known to be smaller on average than those found in deeper waters (Oldham, 1966).

Life History, Location, and Timing

Cusk spawn between March and July in the Northeast Atlantic (Magnusson et al., 1997). On the Scotian Shelf, spawning occurs from May to August and peaks in June (Oldham, 1972; Collette and Klein-MacPhee, 2002), however, cusk in spawning condition have been observed as early as March on the western Scotian Shelf and Gulf of Maine. Cusk are among the most fecund of fishes with greater than 1 million eggs in mature fish greater than 60 cm in length (Oldham, 1966). Cusk eggs are buoyant and hatch 4 mm larvae. Larvae remain in the upper water column and settle to the bottom at approximately 50 mm in length (Harris and Hanke, 2010).

On the Scotian Shelf, 50% of male and female cusk reach maturity at 5 and 7 years, respectively. Consequently, the average age of maturity on the Scotian

Shelf is 6 years. Length at 50% maturity was reported to be 43.5 cm for males and 50.7 cm for females. There is no significant difference in growth rates between the sexes, although males mature more quickly (Oldham, 1966; Oldham, 1972). The otoliths of larger fish are very difficult to read. The oldest fish was aged at approximately 20 years (Magnusson et al., 1997). Recently, radiocarbon dating methods have been used to age cusk from Canadian waters and have resulted in older age estimates. This data suggests that cusk may reach maturity at 10 years, in contrast to previous estimates of 5-6 years (Oldham, 1966).

Known Vulnerabilities

Cusk has been found to be highly vocal. Sound recordings were only done during aggressive behaviour and consisted of a long series of low frequency, short pulses repeated at short intervals (Soldal et al., 2000). The only known major source of human-induced mortality is fishing mortality.

Status Designation

Cusk is under consideration for addition to Schedule 1 of SARA. In 2003, COSEWIC assessed cusk as 'threatened' (COSEWIC, 2003a), which was reconfirmed 2006.

2.8.9 Redfish

Distribution, Habitat, Abundance, and Predator and Prey

Three species of redfish are present in the northwest Atlantic (*Sebastes mentella*, *S. fasciatus,* and *S. marinus* [=*S. norvegicus*]). These three species are similar and nearly impossible to distinguish by their appearance. They are not separated in the fishery and are managed together, although they have different depth preferences and distributions (DFO, 2000; Breeze et al., 2002). Redfish, also known as ocean perch, are a semi-pelagic species occurring on both the Atlantic Ocean in cool waters (i.e. 3-8°C) along the slopes of banks and deep channels in the depths of 100-700 m over rocky, mud, or clay-silt bottom (Scott and Scott, 1988; COSEWIC, 2010). In the Northwest Atlantic, redfish range from Baffin Island in the north to waters off the Gulf of Maine in the south (COSEWIC, 2010) (Figure 2-62). Redfish are common in the Gulf of Maine, in the deeper waters north and west of Georges Bank and, to a lesser extent, on Browns Bank and the continental slope (Pikanowski et al., 1999).

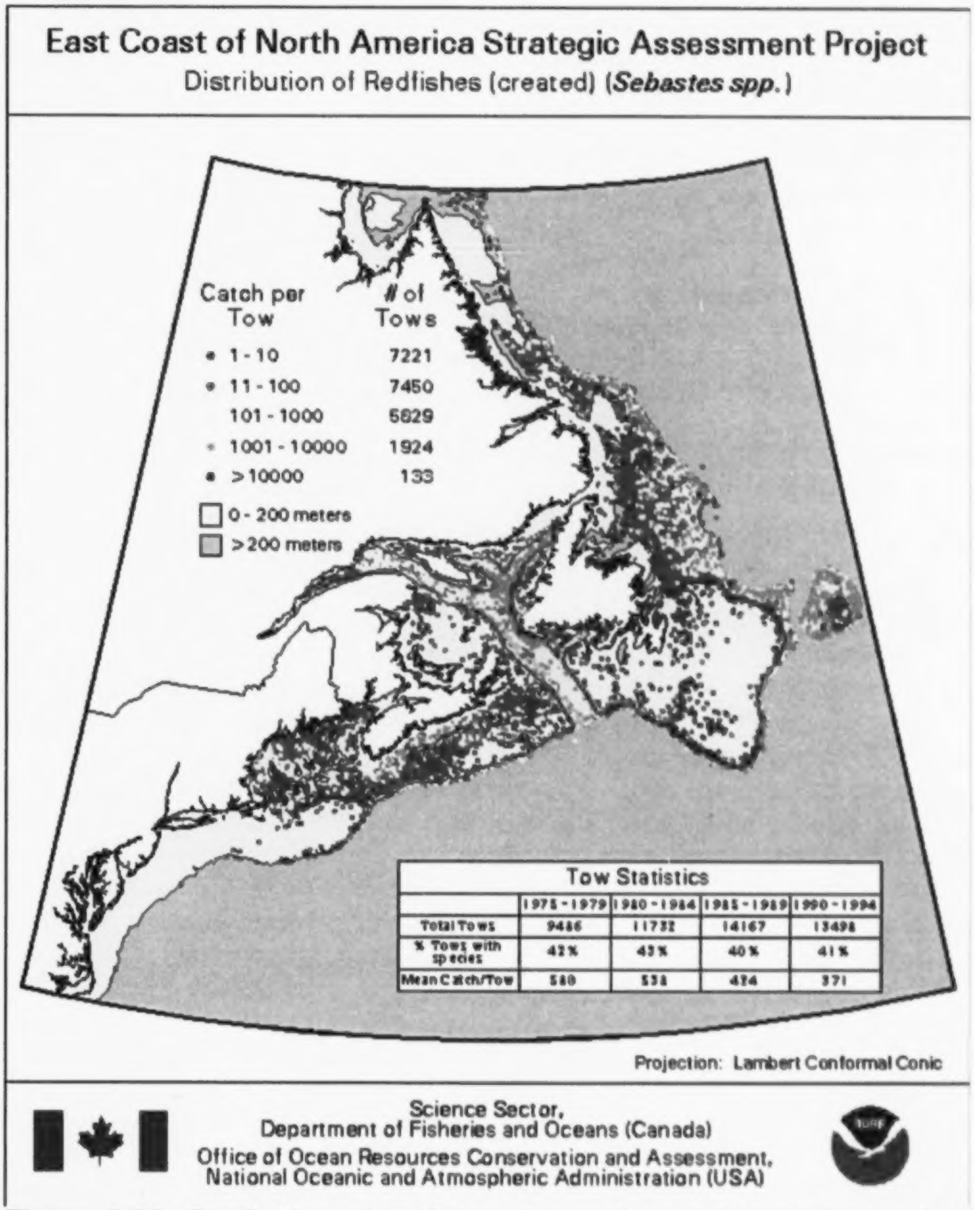

East Coast of North America Strategic Assessment Project
Distribution of Redfishes (created) (Sebastes spp.)
Catch per Tow
# of Tows
1 - 10 7221
11 - 100 7450
101 - 1000 5829
1001 - 10000 1924
>10000 133
0 - 200 meters
>200 meters
Tow Statistics
1975 - 1979
1980 - 1984
1985 - 1989
1990 - 1994
Total Tows 9486 11732 14167 13498
% Tows with species 42% 43% 40% 41%
Mean Catch/Tow 580 538 424 371
Projection: Lambert Conformal Conic
Science Sector,
Department of Fisheries and Oceans (Canada)
Office of Ocean Resources Conservation and Assessment,
National Oceanic and Atmospheric Administration (USA)

Figure 2-62. Distribution of redfish in the northwest Atlantic Ocean based on research trawl surveys conducted by DFO and NOAA from 1975-1994 (Brown et al., 1996).

Except for the area of the Flemish Cap, *S. marinus* is relatively uncommon. *S. fasciatus,* occurring in the deep basins and along the edge of the continental shelf, range predominantly from the southern Grand Banks to the Gulf of Maine where it predominates on Georges Bank and in the Bay of Fundy-Gulf of Maine waters (Figure 2-62). In the deeper waters off the continental shelf and slope, *S. mentella* range predominately from the Gulf of St. Lawrence northward. *S.*

mentella ranges farther north, goes further offshore and into deeper water than *S. fasciatus* and *S. marinus*. The distribution of *S. fasciatus* and *S. mentella* in the Northwest Atlantic follow a north-south gradient with *S. mentella* more abundant in the north of the range whereas *S. fasciatus* are more prevalent in the south (COSEWIC, 2010). The range of both species overlaps in the Laurentian Channel and on the eastern Scotian Shelf and slope (Scott and Scott, 1988; DFO, 2000).

Redfish larvae are released soon after the spring plankton bloom and through the summer production of zooplankton in the Gulf of Maine. They feed on copepod, euphausiids, and fish and invertebrate eggs. Juvenile and adult redfish eat euphausiids, mysids, and fish. They feed most actively at night when they rise off the bottom following the vertical migration of their prey. Fish become increasingly important food as redfish increase in size (Pikanowski et al., 1999). Estimates of population biomass in the management unit, although highly-variable between years, demonstrate no trend over time. With the decline of other groundfish stocks in the early 1990s, fishing pressure on redfish has increased (DFO, 2002b).

Stock and spawning biomass are also increasing. Nonetheless, the spawning stock is currently still at a low level compared to the earlier period in the time series. The Scotian Shelf population (Unit 3) is considered stable, with the average biomass index through the 1990s and early 2000s at only about 7% of what it was in the 1980s. Redfish assessments in Unit 3 (4X and 4W) indicate stability in the population biomass and improved recruitment. This has resulted in an increase in the population biomass to levels greater than that seen during the survey time series (Clark et al., 2010). The U.S. surveys of the Gulf of Maine and Georges Bank region indicate that the biomass of redfish appears to have increased during the early 2000s. Spawning stock biomass in the region increased from 124,000 t in 2001 to 175,800 t in 2004 (Mayo et al., 2007).

Population Structure Relative to Moratorium Area

The stocks consist of a mixture of *S. fasciatus*, which is the predominant species occurring in deep basins and waters along the continental shelf and *S. mentella*, occurring in deep water basins and deeper portions of the continental slope (COSEWIC, 2010). Research indicates that redfish located on the Scotian Shelf belong to a separate stock of *S. fasciatus* from the Gulf of St. Lawrence and Laurentian Channel. There is an indication of a genetic separation between Scotian Shelf and Gulf of Maine populations (DFO, 2002b). Questions remain concerning stock structure and mixing in the Gulf of St. Lawrence and Laurentian Channel, however, there is little evidence for a seasonal change in distribution of redfish on the Scotian Shelf. If redfish make migrations, it is believed that they are less than 100 km in distance (Pikanowski et al., 1999). It is believed that redfish movements are limited, alhtough given their long life span, adults could undertake major long term movements (COSEWIC, 2010).

Life History, Location, and Timing

Redfish are slow-growing, long-lived, and characterized by a low natural mortality rate. Reports have estimated that sexual maturity is reached at 5.5 years (O'Brien et al., 1993) with longevity of up to 75 years (COSEWIC, 2010). Little is known about redfish breeding, but fertilization is internal and fecundity is low. Breeding is thought to occur in the fall from September to December, but fertilization is delayed until February to April. Larvae are released throughout the range of the adults in mid-water from April to August, with a peak in late-May to early-June (Mayo et al., 2007; COSEWIC, 2010). The young are pelagic until they reach approximately 25 mm in size, at which time they move to the ocean floor (Scott and Scott, 1988; COSEWIC, 2010).

Known Vulnerabilities

The life history characteristics of redfish, including late maturity and low fecundity, render this species vulnerable to human impacts.

Status Designation

Redfish is not listed pursuant to SARA, although COSEWIC designated redfish as 'threatened' in April 2010.

2.8.10 Wolffish

Wolffish are a small family of marine fish which inhabit waters of moderate depth in the North Atlantic and North Pacific oceans. Three species occupy the waters of Atlantic Canada, however, the species found most commonly on Georges Bank is the Atlantic wolffish. The northern wolffish, *Anarhichas denticulatus*, occurs mainly in the arctic portions of the North Atlantic. In Canadian waters, it is found from the arctic in the north to the eastern Scotian Shelf in the south (Scott and Scott, 1988). The DFO groundfish surveys on the Scotian Shelf have collected very few individuals, all of which were located in NAFO Division 4V (Figure 2-63).

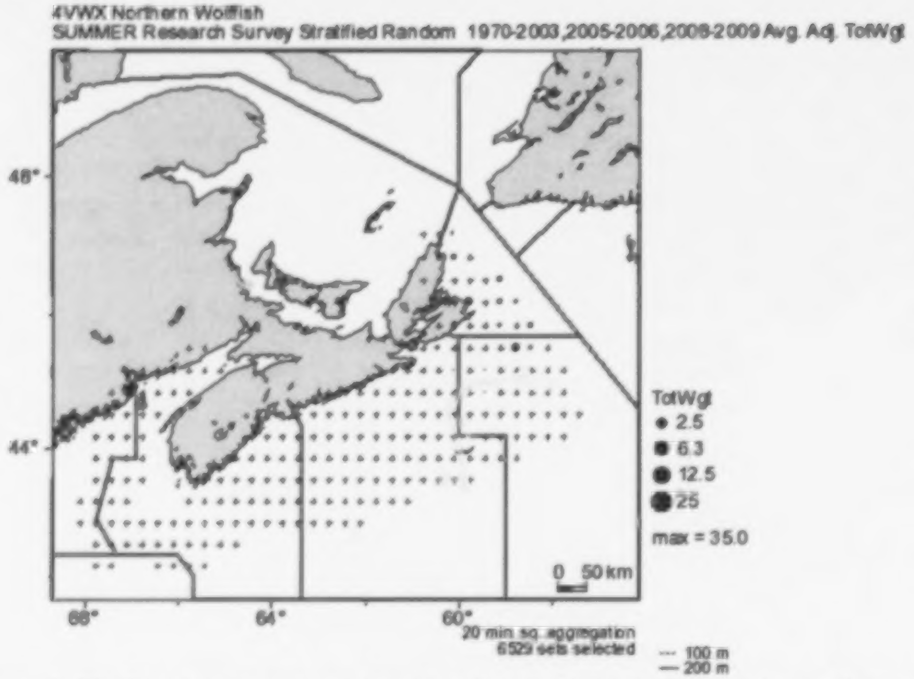

4VWX Northern Wolffish
SUMMER Research Survey Stratified Random 1970-2003,2005-2006,2008-2009 Avg. Adj. TotWgt
48°
44°
68°
64°
60°
TotWgt
● 2.5
● 6.3
● 12.5
● 25
max = 35.0
0 50 km
20 min sq. aggregation
6529 sets selected
--- 100 m
— 200 m

Figure 2-63. Distribution of northern wolfish in the offshore of Nova Scotia from the DFO summer research vessel survey.

The spotted wolffish, *Anarhichas minor*, in the western Atlantic occur from west Greenland, the Grand Banks, and the eastern Scotian Shelf (Scott and Scott, 1988). The DFO groundfish surveys conducted since 1970 have encountered few individuals on the Scotian Shelf with all occurrences coming from 4V (Figure 2-64).

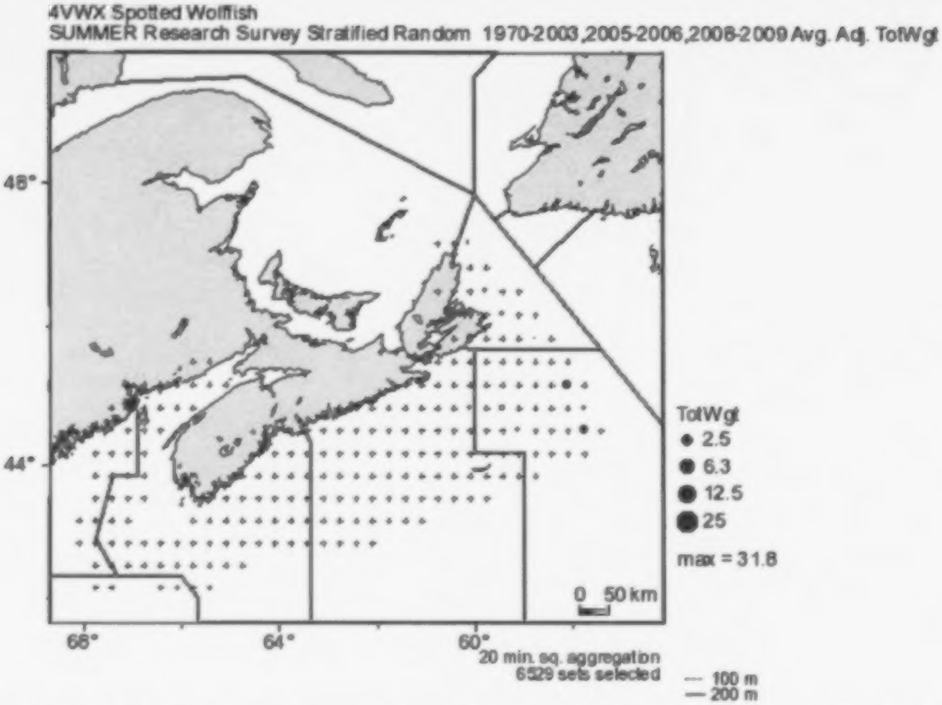

4VWX Spotted Wolffish
SUMMER Research Survey Stratified Random 1970-2003,2005-2006,2008-2009 Avg. Adj. TotWgt
48°
44°
68°
64°
60°
TotWgt
• 2.5
● 6.3
● 12.5
● 25
max = 31.8
0 50 km
20 min. sq. aggregation
6529 sets selected
— 100 m
— 200 m

Figure 2-64. Distribution of spotted wolfish in the offshore of Nova Scotia from the DFO summer Research Vessel Survey.

The Atlantic wolffish, *Anarhichas lupus*, in the western Atlantic, occur from west Greenland south off the coasts of Newfoundland and Nova Scotia and occasionally stray as far south as New Jersey (Scott and Scott, 1988). The DFO groundfish surveys conducted since 1970 have encountered Atlantic wolffish over most of the Scotian Shelf with areas of higher abundance along the edge of the Laurentian Channel, around Brown's Bank, and in the Gulf of Maine (Figure 2-65). The DFO Georges Bank groundfish survey conducted since 1986 has found Atlantic wolffish concentrated along the northern edge of Georges Bank and along the Great South Channel (Figure 2-66).

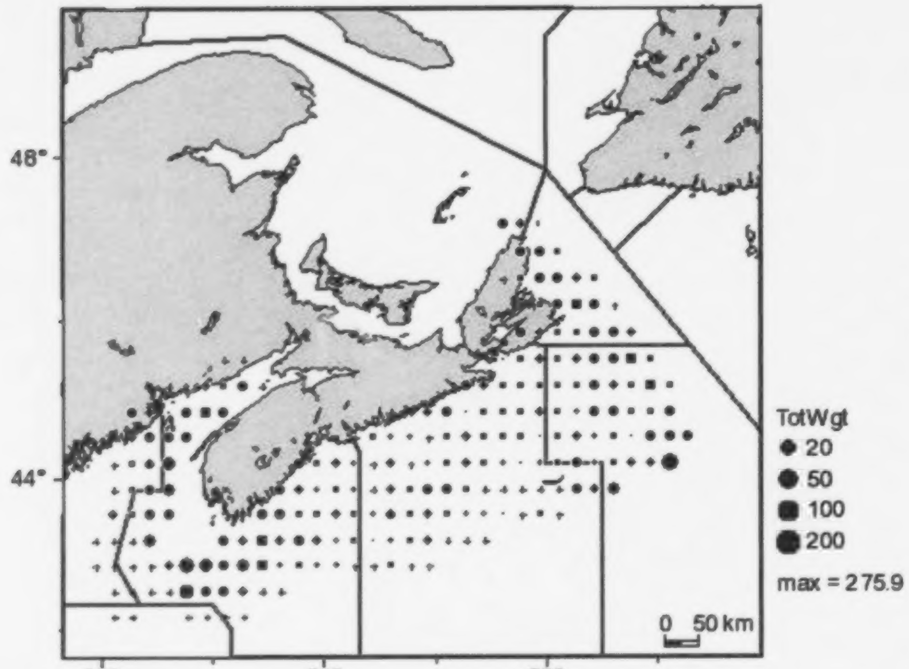

48°
44°
68°
64°
60°
TotWgt
● 20
● 50
● 100
● 200
max = 275.9
0 50 km

Figure 2-65. Distribution of Atlantic wolfish in the offshore of Nova Scotia from the DFO summer research vessel survey.

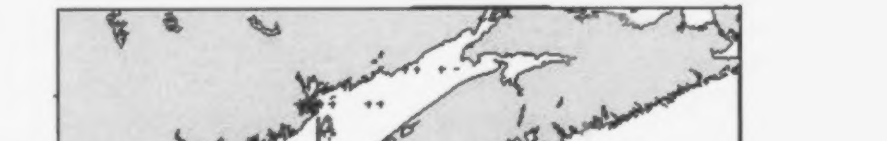

44°
42°
40°
70°
68°
66°
64°
62°
TotWgt
● 10
● 25
● 50
● 100
max = 139.0
0 40 km

Figure 2-66. Distribution of Atlantic wolfish on Georges Bank from the DFO Georges Bank research vessel survey.

2.8.10.1 Atlantic Wolffish

Distribution, Habitat, Abundance, and Predator and Prey

The Atlantic wolffish, *Anarhichas lupus,* is widely distributed on both sides of the North Atlantic. In the western Atlantic it is distributed from the Davis Strait in the north to the Nantucket Shoals in the south (Nelson and Ross, 1992). In Canadian waters, the greatest abundance occurs off the coast of Newfoundland. Wolffish are widely distributed over the entire Scotian Shelf and in the Bay of Fundy. Higher abundances occur in NAFO Division 4V along the Laurentian Channel and in 4X around Browns Bank and the Gulf of Maine (McRuer et al., 2000). Wolffish are distributed throughout the southern Gulf of Maine and Georges Bank area, however, concentrations can be found along the 100 m contour from the Northeast Peak to Jeffery's Ledge and along the Great South Channel (Nelson and Ross, 1992).

The Atlantic wolffish is solitary and sedentary and is found at depths up to 350 m (Albikovskaya, 1982). On the Scotian Shelf their preferred depth range is 75-130 m, with a preferred temperature range of 3-6°C (Scott and Scott, 1988). In the southern Gulf of Maine and Georges Bank area their preferred depth range is 22-275 m (Nelson and Ross, 1992). They are found predominantly on rocky and hard clay bottoms (Nelson and Ross, 1992), however, they have been found in holes under large boulders when in shallow waters (Scott and Scott, 1988). The diet of Atlantic wolffish is composed primarily of benthic invertebrates (Scott and Scott, 1988). The diet in the Scotian Shelf to Labrador region consists mainly of whelks, brittle stars, sea urchins, sand dollars, hermit crabs, and bivalves in decreasing order of importance (Templeman, 1985). In the Gulf of Maine and Georges Bank area, it was found that bivalves were the most important prey item, followed by echinoderms, gastropods, and decapods (Nelson and Ross, 1992).

Surveys from most parts of the western Atlantic indicate declines in abundance of Atlantic wolffish over the past 20 years. Since 1978, catch rates in Newfoundland have been down by 91% over two generations. Mean size has also declined and is now smaller than the size of maturity off Newfoundland. The stock is considered overexploited and depleted (COSEWIC, 2000). Surveys on the Scotian Shelf have also shown a decline through the 1980s, which has continued through to 2009 (Figure 2-67). Scotian Shelf surveys have also shown a decline in mean length and mean weight from a high in 1984 (mean length 55.4 cm and mean weight 2.5 kg) to a low in 2000 (mean length 37.9 cm and mean weight 1.4 kg). The DFO surveys on Georges Bank began in 1986 and show a steady decline over the time series (Figure 2-68).

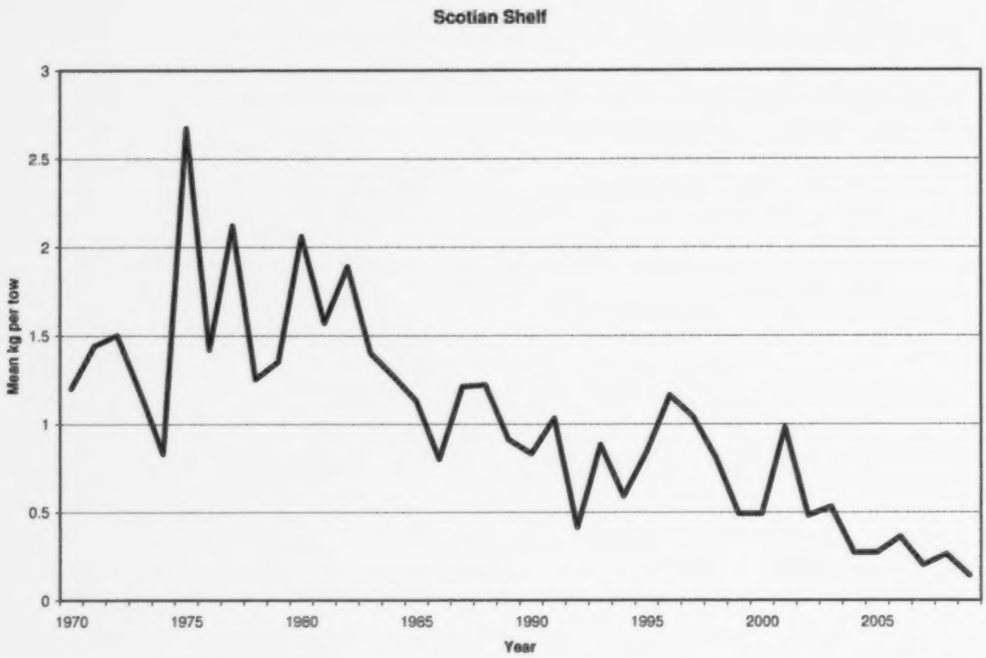


Figure 2-67. Biomass (kg tow^{-1}) of Scotian Shelf Atlantic wolffish from the DFO summer research vessel survey.

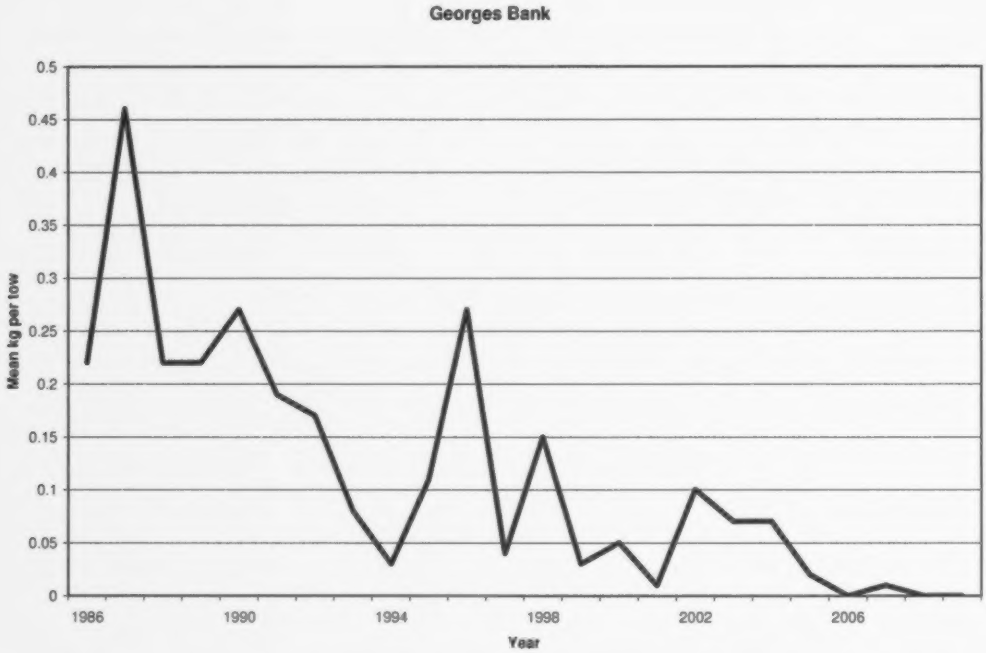


Figure 2-68. Biomass (kg tow^{-1}) of Georges Bank Atlantic wolffish from the DFO research vessel survey.

Population Structure Relative to Moratorium Area

The population structure of Atlantic wolffish in the Gulf of Maine and Georges Bank area is unknown (DFO, 2002c). The species has a sedentary nature and movements seem to be limited to small scale spring spawning migrations to shallower waters (Nelson and Ross, 1992). It is possible that there may be small sub-populations of Atlantic wolffish in the area.

Life History, Timing, and Locations

The Atlantic wolffish spawning times vary greatly across its range. Off the east coast of Newfoundland, some Atlantic wolffish migrate to shallow waters in late spring with spawning taking place in mid-September (Scott and Scott, 1988). On the Scotian Shelf, egg masses have been found as early as February (McRuer et al., 2000). The fecundity of Atlantic wolffish is considered to be low, however, survival is considered to be relatively high (Scott and Scott, 1988). Atlantic wolffish deposit their eggs in a cohesive mass that is guarded by the male (Scott and Scott, 1988). On hatching, the larvae are pelagic and around 17 mm in length. The larvae remain close to the bottom and the entire larval stage is spent close to the spawning site (Collette and Klien-MacPhee, 2002). It is estimated that Atlantic wolffish reach sexual maturity between 8-10 years of age (Scott and Scott, 1988).

Known Vulnerabilities

Atlantic wolffish are characterized by low fecundity, relatively late age at maturation, sedentary lifestyle, benthic cohesive egg masses, and larval site fidelity. Given these factors and the poor understanding of the population structure of Atlantic wolffish, it is possible that a relatively localized mortality or reproductive disturbance could put a sub-population at risk.

Status Designation

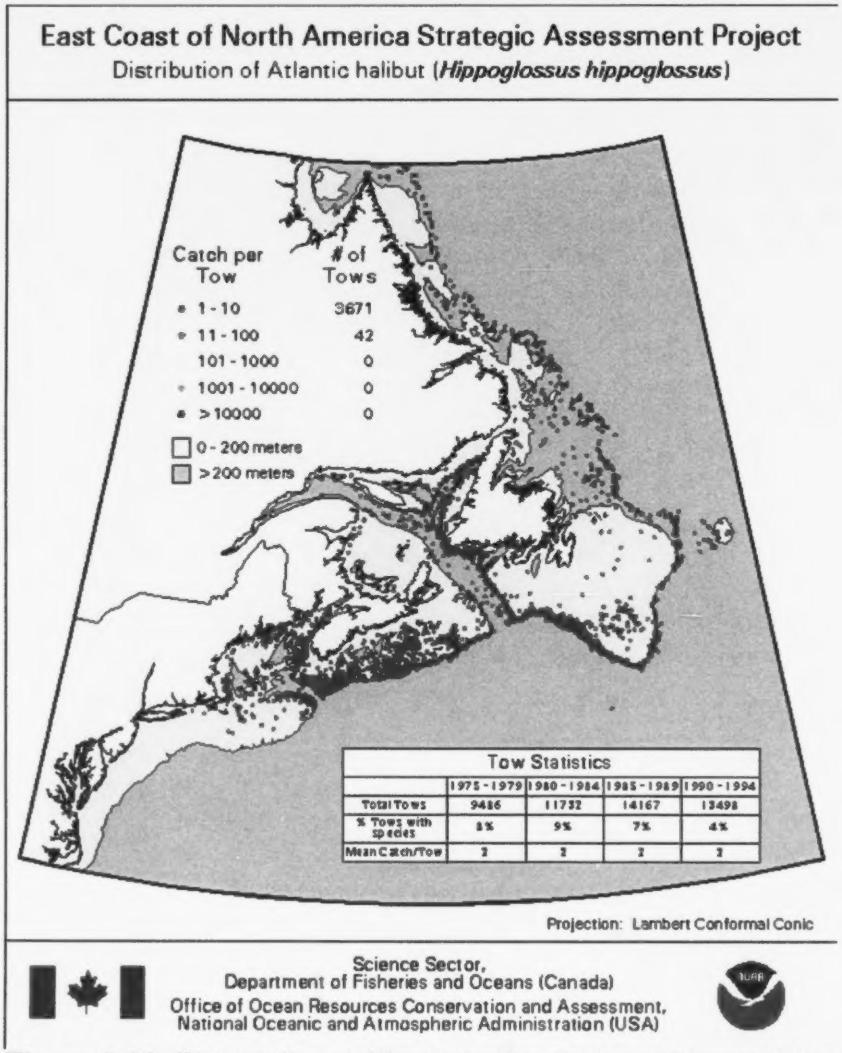
The Atlantic wolfish is listed as 'special concern' pursuant to SARA. It was designated as 'special concern' by COSEWIC in November 2000.

2.8.11 Atlantic Halibut

Distribution, Habitat, Abundance, and Predator and Prey

Atlantic halibut, *Hippoglossus hippoglossus*, in the northwest Atlantic are distributed from north of Labrador south to Virginia and also occur off Western Greenland. They are considered a single population throughout their range (Scott and Scott, 1998). In Canadian waters, halibut range from the coast of Labrador, the Gulf of St. Lawrence, the eastern shores of Nova Scotia and Bay of Fundy

(Figure 2-69), and are most abundant along the southern edge of the Grand Banks and on the Scotia Shelf from Browns Bank to Banquereau Bank (Cargnelli et al., 1999). Juvenile halibut are quite localized, being found in nursery grounds and on coastal areas 20-60 m deep with sandy bottoms. Adults are found over sand, gravel, or clay substrates and prefer temperatures greater than 4°C (Cargnelli et al., 1999). On the Scotian Shelf, halibut are most abundant between 200-500 m water depth and can be found in deep channels between banks and at the edge of the continental shelf over sand, gravel, or clay substrates. Halibut move from shallower into deeper water in the winter, returning to shallow waters in summer (Scott and Scott, 1998; DFO, 2009d).


East Coast of North America Strategic Assessment Project
Distribution of Atlantic halibut (*Hippoglossus hippoglossus*)
Catch per Tow
# of Tows
● 1-10 3671
● 11-100 42
101-1000 0
● 1001-10000 0
● >10000 0
☐ 0-200 meters
▨ >200 meters
Projection: Lambert Conformal Conic
Science Sector,
Department of Fisheries and Oceans (Canada)
Office of Ocean Resources Conservation and Assessment,
National Oceanic and Atmospheric Administration (USA)

Tow Statistics

	1975-1979	1980-1984	1985-1989	1990-1994
Total Tows	9486	11732	14167	13498
% Tows with species	8%	9%	7%	4%
Mean Catch/Tow	2	2	2	2

Figure 2-69. Distribution of Atlantic halibut in the northwest Atlantic Ocean based on research trawl surveys conducted by DFO and NOAA from 1975-1994 (Brown et al., 1996).

As halibut increase in size, prey selection shifts from invertebrates to fish. Small halibut feed on cephalopods, large crustaceans, and benthic invertebrates including shortfin squid, hermit and small crabs, prawns, and mysids, while larger halibut consume cod, haddock, sand lance, redfish, pollock, wolffish, herring, and capelin (Cargnelli et al., 1999). Since the early 1990s, there appears to have been a significant reduction in the numbers of halibut in the northern and southern extent of its range, in U.S. waters (Kanwit, 2007), and along the Labrador Shelf.

The biomass of Atlantic halibut on the Scotian Shelf and Southern Grand Banks (3NOPs4VWX5Zc) has increased since 2003. The biomass estimate varies from 6498-8333 t, with an annual increase of 252 t per year over the entire stock unit and 315 t per year in 4VWX (DFO, 2009d). The DFO RV and halibut surveys indicate that the number of pre-recruits (fish greater than 81 cm in length) is above the long-term average (0.192 halibut per standard tow) and has been increasing since 2004. Surveys completed by the Northeast Fishery Science Center indicate that biomass in the Gulf of Maine and Georges Bank remains very low. Population size indices have fluctuated considerably since the 1960s and have declined overall. The survey indices for 2002-2005 ranged from a high of 554 t in 2004 to a low of 83 t in 2005 (Mayo and Terceiro, 2005).

Population Structure Relative to Moratorium Area

The stock structure of Atlantic halibut is not well defined. The majority of fish do not move between NAFO divisions, however, individuals may roam extensively within their range (Scott and Scott, 1998) and are considered a transboundary stock. Tagging studies have documented long distance migrations from Labrador to Greenland, the Gulf of St. Lawrence to Iceland, and the Scotian Shelf to the Grand Banks. Migrations of larger fish to deeper water in autumn are thought to be related to spawning. Studies have shown that the Browns Bank area may be an important rearing area for juvenile halibut populating the Scotian Shelf and southern Grand Banks. Juveniles emigrate from nursery areas at 3-4 years and undergo north-eastward movement as they grow (Cargnelli et al., 1999).

Life History, Location, and Timing

Halibut are sexually dimorphic, with females being substantially larger than males. Halibut live up to 50 years and reach sexual maturity at ages 5 and 9, respectively, for males and females (Trzcinski et al., 2009). The median age in the Gulf of Maine and Georges Bank region is approximately 7 years (Sigourney et al., 2006). Females are batch spawners, producing several batches of eggs each year. Spawning is thought to occur in waters along the slope of banks and the continental slope at depths of 200 m or greater during late fall, winter and early spring, peaking from November to December. Eggs are suspended in the water column from 54-200 m below the surface and are thought to develop near the seabed. Settlement is thought to occur at 34-40 mm in length (Cargnelli et al., 1999).

Known Vulnerabilities

The vulnerabilities of Atlantic halibut are not known.

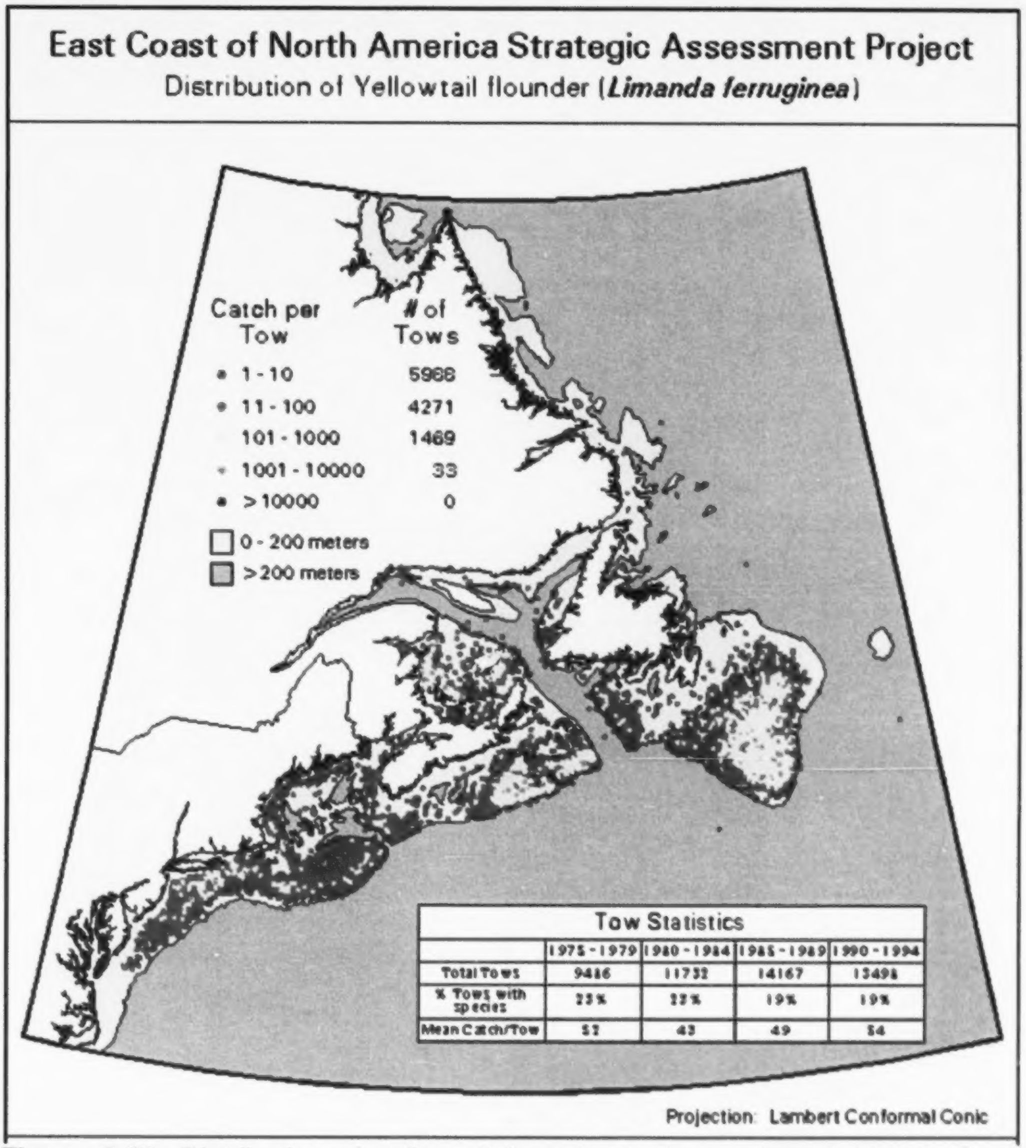
Status Designation

Atlantic halibut is not listed pursuant to SARA and has not been evaluated by COSEWIC.

2.8.12 Yellowtail Flounder

Distribution, Habitat, Abundance, and Predator and Prey

Yellowtail flounder, *Limanda ferruginea*, is a small-mouthed Atlantic flatfish species that inhabits sandy substrates in relatively shallow waters of the continental shelf of the western north Atlantic from southern Labrador to Chesapeake Bay (Figure 2-70) (Bigelow and Schroeder, 1953, TRAC, 2009d). A major concentration of yellowtail flounder occurs on Georges Bank from the Northeast Peak to the Great South Channel (Legault et al., 2009). On Georges Bank, adult yellowtail flounder are found primarily at depths between 37-73 m, where they show a preference for sand or sand-mud sediments (Scott and Scott, 1988; Johnson et al., 1999).


East Coast of North America Strategic Assessment Project
Distribution of Yellowtail flounder (*Limanda ferruginea*)
Catch per Tow
# of Tows
1 - 10 5988
11 - 100 4271
101 - 1000 1469
1001 - 10000 33
>10000 0
0 - 200 meters
>200 meters
Projection: Lambert Conformal Conic

Tow Statistics

	1975 - 1979	1980 - 1984	1985 - 1989	1990 - 1994
Total Tows	9486	11732	14167	13498
% Tows with species	23%	23%	19%	19%
Mean Catch/Tow	53	43	49	54

Figure 2-70. Distribution of yellowtail flounder in the northwest Atlantic Ocean based on research trawl surveys conducted by DFO and NOAA from 1975-1994 (Brown et al., 1996).

Yellowtail flounder have a small mouth that restricts their choice of food. They feed primarily on benthic macrofauna, with prey consisting of amphipods, polychaete worms, mysids, and sand dollars, as well as small quantities of other invertebrates and small fishes (Langton, 1983; Hahm and Langton, 1984; Collie, 1987; Johnson et al., 1999; Bruno et al., 2000). Arthropods and annelids dominated the yellowtail flounder stomach contents collected during the NEFSC spring survey of Georges Bank between 1973-1990 (Johnson et al., 1999). Yellowtail flounder feed primarily during daylight hours. Studies from NAFO

Divisions 3NO demonstrated that stomachs contained the least amount of food at dawn and the most at dusk, indicating that feeding began near sunrise and ended near sunset (Bruno et al., 2000). Similarly, the highest stomach content weights occurred in the afternoon to early evening in samples collected from southern New England and Georges Bank (Langton, 1983).

The Georges Bank yellowtail flounder stock is jointly managed by the Canada and the U.S. through the Transboundary Management Guidance Committee (TMGC). Stock assessments are conducted annually by the Transboundary Resources Assessment Committee (TRAC). Estimates of abundance are based on bottom trawl survey observations and the range of results from plausible age structured analytical assessments (i.e Virtual Population Analysis, or VPA) that use fishery catch statistics and sampling for size and age composition of the catch. The VPAs were calibrated to trends in abundance from three bottom trawl survey series (U.S. NMFS spring, NMFS fall, and DFO Georges Bank spring) and a recruitment index from the NMFS summer sea scallop survey. In 2008 and 2009, the DFO surveys recorded individual tows that were much larger than any seen previously in the time series. These individual tows had a strong influence on the estimates for those years, so two VPAs were run, one with and one without the 2008 and 2009 DFO survey data (Legault et al., 2009) (Figure 2-71).

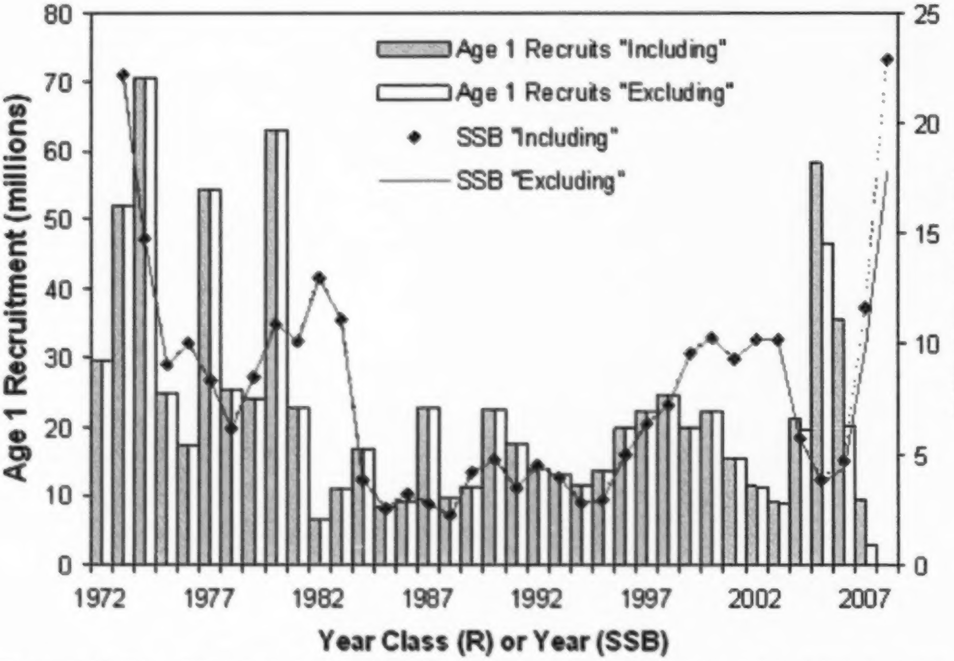


Figure 2-71. Spawning Stock Biomass, or SSB (lines), and Age 1 recruitment (bars) of yellowtail flounder. 'Including' refers to the VPA run that included the DFO 2008 and 2009 survey information and 'Excluding' refers to the VPA run that excluded it (TRAC, 2009d).

Yellowtail flounder adult biomass (age 3+) increased from a low of 2100 t in 1995 to 11,000 t in 2003, declined to 3300 t in 2006, and increased to 20,600 t (excluding the 2008/2009 DFO surveys in the VPA) or 28,000 t (including the 2008/2009 DFO surveys in the VPA) at the beginning of 2009. This was the highest adult biomass observed since 1973. Spawning stock biomass in 2008 was estimated to be 17,800 t (excluding the 2008/2009 DFO surveys) or 22,900 t (including the 2008/2009 DFO surveys). From 1998 to 2001, recruitment averaged 22.3 million fish at age 1, but has been below 20 million fish since then. The exception has been the above average 2005 year-class estimated at 46.6 million fish, which is the strongest year-class since the 1980 cohort (TRAC, 2009d).

Population Structure Relative to Moratorium Area

The management unit currently recognized by Canada and the U.S. for the transboundary Georges Bank yellowtail flounder stock includes the entire Bank east of the Great South Channel to the Northeast Peak (Gavaris et al., 2005). Tagging observations, larval distribution, life history traits, geographic patterns of landings, and survey data indicate that Georges Bank yellowtail flounder from this management unit comprise a relatively discrete stock, separate from those on the western Scotian Shelf, off Cape Cod and southern New England (Royce et al., 1959; Lux, 1963; Neilson et al., 1986; Begg et al., 1999; Cadrin, 2003; Stone and Nelson 2003; Stone et al., 2004), with little movement into the adjacent stock areas (Cadrin, 2006). Tagging on the U.S. side of Georges Bank has demonstrated frequent movements in the stock area, where fish moved an average of 42 km between their release and recapture sites, with differences in distance traveled based on fish gender and season of recapture (Cadrin et al., 2004; Zeiber, 2008). Vertical off-bottom migration during the evening hours has also been demonstrated using archival tags (Cadrin and Moser, 2006).

Life History, Location, and Timing

Yellowtail spawning occurs on Georges Bank from late-March until early-August, peaking in May. From the distribution of both ichthyoplankton and mature adults, it appears that spawning occurs on both sides of the Canada and U.S. boundary line. Yellowtail flounder mature earlier than most flatfish, with approximately half of the age 2 females being mature and nearly all of the age 3 females being mature (Legault et al., 2009). Yellowtail flounder are batch spawners (Murua and Saborido-Rey, 2003), depositing their eggs on or near the bottom. After fertilization, the buoyant eggs float to the surface where they drift during development (Legault et al., 2009).

The eggs hatch after approximately 1-3 weeks depending on the water temperature, with the most dense egg concentrations occurring on the northeast and southwest part of Georges Bank (Johnson et al., 1999). Larvae are pelagic for a month or more and then they become demersal and settle to benthic habitats (Legault et al., 2009). The larvae are found on Georges Bank from April to August, with the highest concentrations occurring in June (Johnson et al., 1999). In the spring, juvenile and adult yellowtail flounder are concentrated on the southern edge and northeast peak of Georges Bank, but they are more widely distributed across the Bank at other times of year.

Known Vulnerabilities

Georges Bank yellowtail flounder is a bottom dwelling fish that does not migrate off the Bank. It makes use of sand and sand/mud substrate on the Bank, lays its eggs on or near the bottom, and feeds on benthic macrofauna. As a result, it may be vulnerable to any disturbance to the bottom.

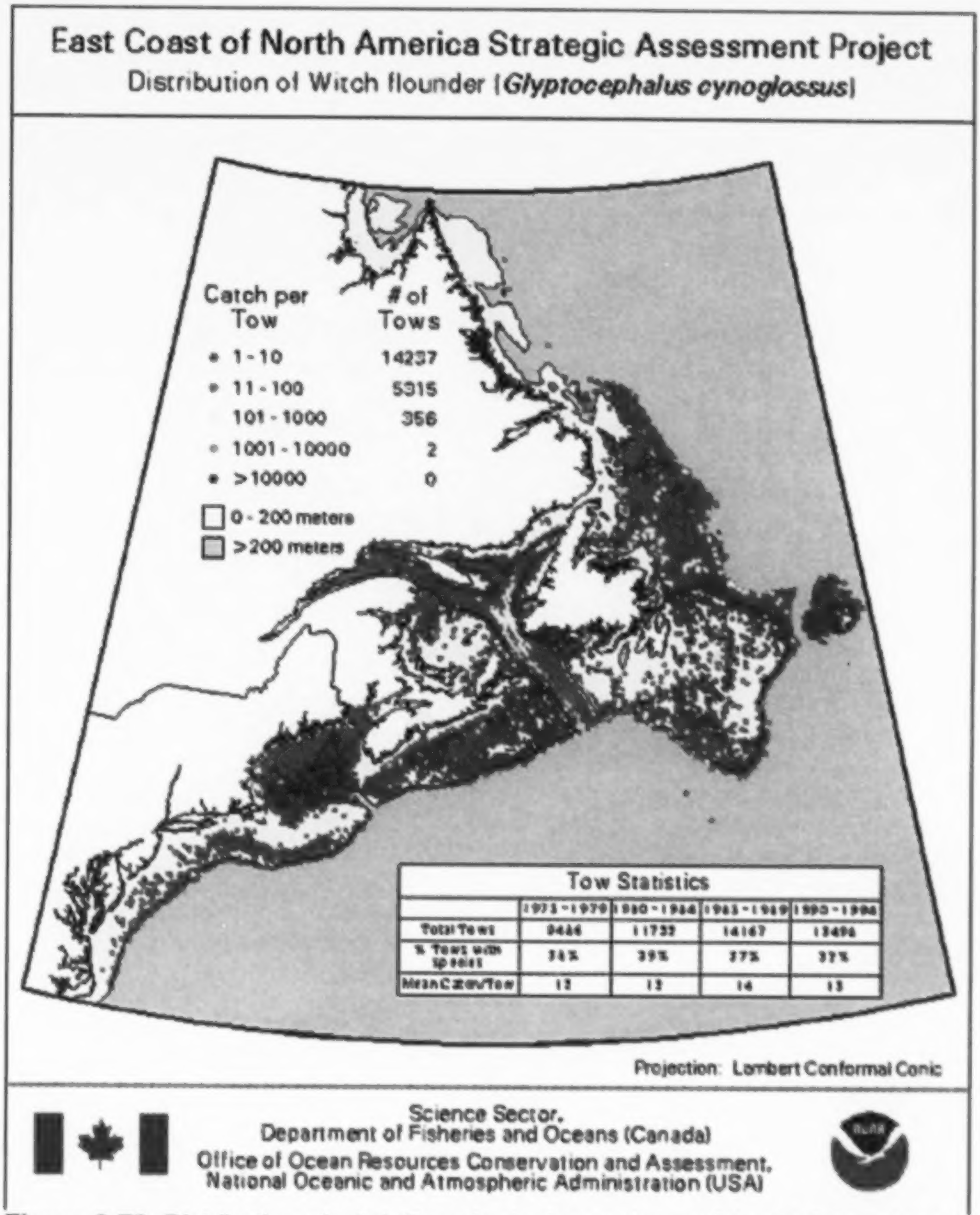
Status Designation

Yellowtail flounder is not listed pursuant to SARA and has not been evaluated by COSEWIC.

2.8.13 Witch Flounder

Distribution, Habitat, Abundance, and Predator and Prey

Witch flounder, *Glyptocephalus cynoglossus*, is a deep water boreal flatfish occurring on both sides of the North Atlantic. In the northwest Atlantic, witch flounder are distributed from Labrador to Georges Bank and in the continental slope waters southward to Cape Hatteras, usually at 50-300 m in water of 2-6^{o}C (Figure 2-72). They occur most commonly in deep holes and channels and along the shelf slope on muddy bottoms. There is no evidence of extensive migrations, but there are seasonal changes in concentration associated with spawning (McRuer et al., 1997; Scott and Scott, 1988).


East Coast of North America Strategic Assessment Project
Distribution of Witch flounder (*Glyptocephalus cynoglossus*)
Catch per Tow
# of Tows
1-10
14237
11-100
5315
101-1000
356
1001-10000
2
>10000
0
0-200 meters
>200 meters
Projection: Lambert Conformal Conic
Science Sector,
Department of Fisheries and Oceans (Canada)
Office of Ocean Resources Conservation and Assessment,
National Oceanic and Atmospheric Administration (USA)

Tow Statistics

	1975-1979	1980-1984	1985-1989	1990-1994
Total Tows	9446	11732	14167	13496
% Tows with Species	34%	39%	37%	37%
Mean Catch/Tow	12	12	14	13

Figure 2-72. Distribution of witch flounder in the northwest Atlantic Ocean based on research trawl surveys conducted by DFO and NOAA from 1975-1994 (Brown et al., 1996).

Witch flounder diet consists of polychaete worms, benthic invertebrates such as small crustaceans, bivalve molluscs and echinoderms and rarely small fish. There is a distinct shift in diet with polychaetes increasing in importance with age.

By sexual maturity, polychaetes dominate the diet (Wigley et al., 2003). The 1997 stock status report for witch flounder on the Scotian Shelf reported that populations declined substantially in abundance between the mid-1980s and the mid-1990s, and the harvest portion of the population was at the lowest level observed at that time. A 2003 assessment of the Gulf of Maine and Georges Bank population in U.S. waters indicated that abundance sharply increased in 1993 and had continued to increase to near record levels in 2002, however, the age composition still remains truncated with a striking decline in the number of older fish (Wigley et al., 2003).

Population Structure Relative to Moratorium Area

The stock structure of witch flounder is not known. Witch flounder are a rather sedentary species that do not undertake long-distance migration, with concentrations of witch flounder in the western 4X continuous with those in the rest of the Gulf of Maine. (DFO, 2002b; Wigley et al., 2003).

Life History, Location, and Timing

Female witch flounder live longer and grow larger than males (Scott and Scott, 1988). Median age at sexual maturity for male witch flounder is 4 years and 6.5 years for females. Witch flounder spawn from March to November, with peak spawning occurring in summer. The general trend is for spawning to occur progressively later from south to north. In the Gulf of Maine-Georges Bank region, spawning occurs in dense aggregations associated with areas of cold water from April to November and peaks from May to August. The western and northern areas of the Gulf of Maine tend to be the most active spawning sites. Spawning occurs at or near the bottom, although the buoyant eggs rise into the water column where subsequent egg and larvae development occurs. Hatching occurs 7-8 days after spawning. The post-larval pelagic phase is usually long, lasting up to one year, and it is thought that the first few years of demersal life are spent in much deeper water than the adults (DFO, 2002b; Wigley et al., 2003).

Known Vulnerabilities

Witch flounder is a bottom dwelling species. Given the benthic nature of the species it is possible that witch flounder may be vulnerable to bottom activities causing disturbances or contamination.

Status Designation

Witch flounder is not listed pursuant to SARA and has not been evaluated by COSEWIC.

2.8.14 Skates

Scotia-Fundy and U.S. RV survey data was examined to determine the distribution and relative abundance of the most common skate species found to occur on the Northeast Peak of Georges Bank. Skate species caught in order of abundance during the Canadian RV survey are: winter skate (*Leucoraja ocellatta*); little skate (*Leucoraja erinacea*); thorny skate (*Amblyraja radiate*); barndoor skate (*Dipturus laevis),* and smooth skate (*Malacoraja senta*).Two other species, the rosette skate (*Leucoraja garmani*) and the clearnose skate *(Raja eglanteria*), have been reported from U.S. waters but are not common on Georges Bank.

Winter skate and little skate are the most abundant skate species on the Northeast Peak. They are widely distributed across the entire Bank. Since 1987, no trend in abundance is evident in either species. Winter and little skate are sympatric over most of their ranges and are often difficult to distinguish, especially when immature. Thorny skate are the third most common skate species caught during the Canadian RV survey and are found on the edges of the Northeast Peak and north of the Great South Channel in the Gulf of Maine. Thorny skate abundance has declined on the Northeast Peak since the early 1990s to very low levels. Barndoor skate are caught primarily on the southern flank of Georges Bank, with no separation in the distribution between the Canadian and U.S. zones. Smooth skate are not commonly caught during the Canadian RV survey given the depth distribution of the survey sets. They are found on the edges of the Bank in the Canadian zone and in the Gulf of Maine in the same area as thorny skate. Smooth skate and barndoor skate abundance has remained low, without any obvious trend since the beginning of the time series.

2.8.14.1 Winter Skate

Distribution, Habitat, Abundance, and Predator and Prey

Winter skate, *Leucoraja ocellata,* are found from Cape Hatteras to the Gulf of St. Lawrence/southern coast of Newfoundland, based on Canadian and U.S. RV survey data (Simon et.al. 2003; COSEWIC 2005a; NEFSC, 2007). The highest concentrations have been found on Georges Bank and the offshore banks of the Scotian Shelf. In this broad geographic range, winter skate have been reported from less than 1m in depth to 371 m depth (Scott and Scott, 1988; McEachern, 2002). The Canadian RV winter survey of Georges Bank indicated that winter skate is abundant throughout Georges Bank, with the highest concentrations residing on the U.S. side of the Bank (Figure 2-73). Approximately 70% of the sets in this survey contained winter skate. The area of occupancy of this species has been stable. Winter and little skate are sympatric over most of their ranges and are often difficult to distinguish, especially when immature.

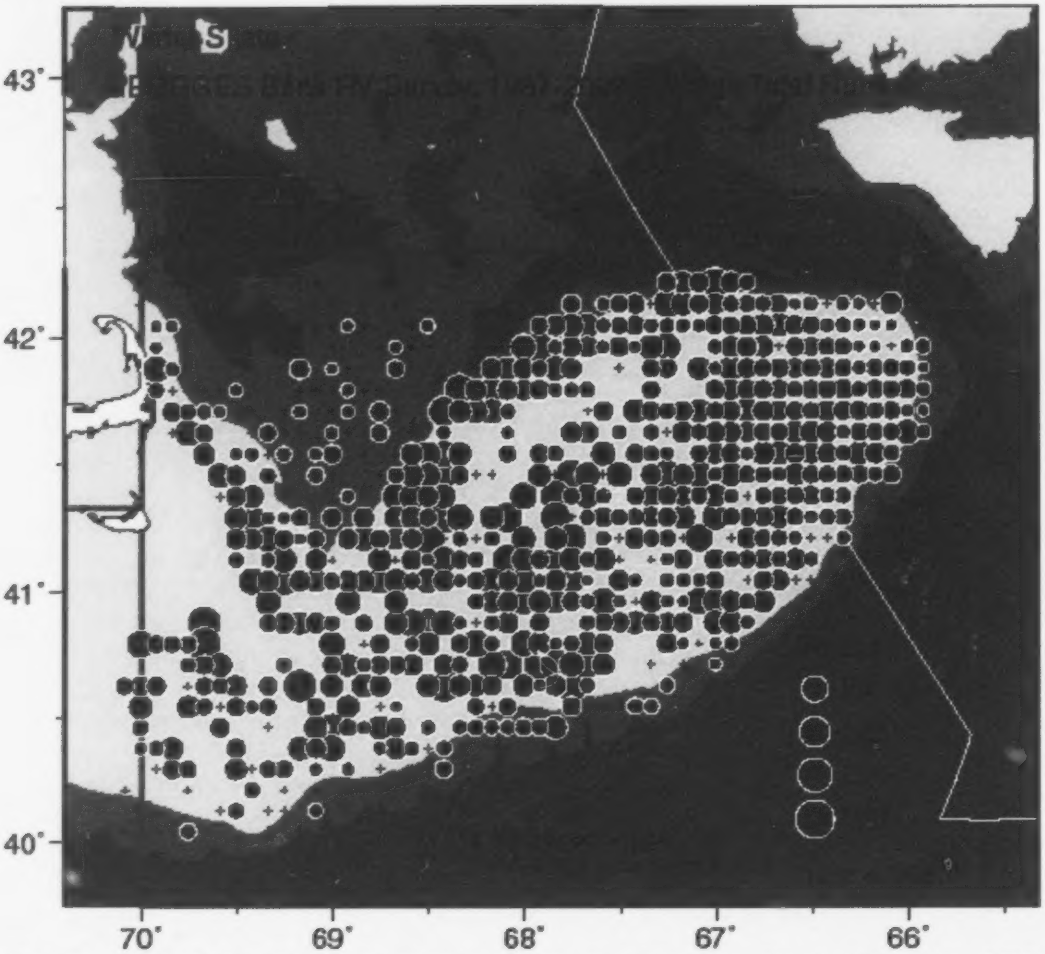


Figure 2-73. Distribution of winter skate on Georges Bank from the DFO Georges Bank RV survey.

Crustaceans make up more than 50% of the diet of Georges Bank winter skate greater than 61 cm in length, while fish dominate the diet of skate greater than 91 cm in length. Among the most common prey items for all sizes of skate are sand shrimps, Jonah crab, rock crab, hermit crab, isopods, and sand lance. Other fish prey includes silver hake, herring, longhorn sculpins, and other skates (McEachern et al., 1976; Packer et al., 2003a).

The population biomass of Eastern Georges Bank winter skate, as calculated from the Canadian RV survey, has fluctuated between 800-5900 t from 1987-2009 without trend, although the 2009 estimate is the highest in the series (Figure 2-74). Abundance (number per tow) was generally higher in the beginning of the series, declined to a low in 1997, and has since recovered to near average values. The larger scale spring and fall U.S. RV surveys were examined from 1967-2006, in order to put the results of the Canadian RV data into a broader context. In general, abundance was low in both surveys until 1980, increased rapidly to a peak in the mid 1980s, and subsequently fell to estimates seen in the beginning of the two surveys (NEFSC, 2007).

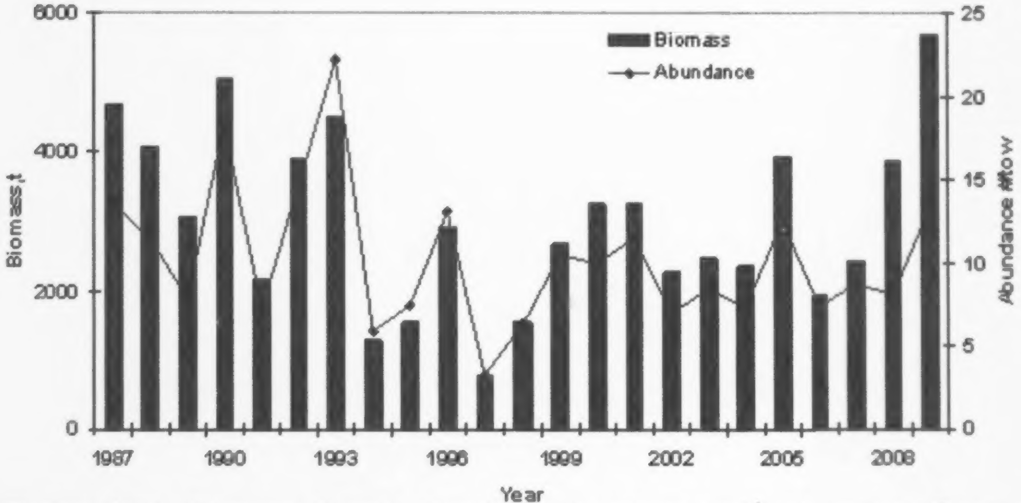


Figure 2-74. Biomass (t) and abundance (numbers tow^{-1}) of eastern Georges Bank winter skate.

Population Structure Relative to Moratorium Area

The U.S. RV seasonal surveys indicate that winter skate are widely distributed in the spring over the Georges Bank region south to Cape Hatteras, while in the fall adults are more concentrated on the Bank (NEFSC, 2007). The U.S. nearshore RV surveys also suggest that juveniles exhibit an onshore-offshore seasonal migration (NEFSC, 2007). Given the continuous distribution of winter skate, as demonstrated in Figure 2-73, there is a high likelihood that the fish on both sides of the border constitute a single population on Georges Bank. The relationship between winter skate on Georges Bank and Browns Bank is unknown although, given the depth preferences of the species and the depth of the Fundian Channel, it is unlikely that there is wide scale movement between these two locations.

Life History, Location, and Timing

Skate are oviparous, depositing a single egg in a leathery capsule (purse), which is extruded. The purse has adhesive mucus that attaches to substrate materials and helps it to maintain contact with the bottom. Observations suggest that it may take as long as 22 months for the purse to hatch on the Scotian Shelf, but no such observations exist for Georges Bank (Simon and Frank, 1998). It is likely that less than 100 purses per female are produced per year. In the western Gulf of Maine, a peak in purse production was observed from September to November, although winter skate have also been observed with purses throughout the year (Packer et al., 2003a). On the Scotian Shelf, deposition of egg-cases has been observed in the fall (Simon and Frank, 1998). This suggests that winter skate 'spawn' in the Georges Bank moratorium area in the fall, but spatial and temporal details are unknown. Upon hatching, the juveniles are approximately 12 cm in length (Sulikowski et al., 2003).

Known Vulnerabilities

Winter skate life history characteristics increase its vulnerability to exploitation, reduce its rate of recovery, and increase its risk of extinction (Swain et al., 2006). Such characteristics include: delayed age at maturity; long generation time; low fecundity; and slow population growth rate. Given the benthic nature of juveniles and adults, it is possible that winter skate may be vulnerable to industrial discharges. The life stage that would be most vulnerable to bottom disturbances would be skates purses, due to the length of time that it takes them to hatch and their sessile nature.

Status Designation

The Georges Bank-Western Scotian Shelf-Bay of Fundy population of winter skate is not listed pursuant to SARA, although it has been designated as 'special concern' by COSEWIC.

2.8.14.2 Little Skate

Distribution, Habitat, Abundance, and Predator and Prey

Little skate, *Leucoraja erinacea,* are found from Cape Hatteras to the Sable Island Bank on the Scotian Shelf, based on U.S. and Canadian RV survey data (NEFSC, 2007). They are most abundant on Georges Bank and in southern New England waters. The distribution pattern from the Canadian RV survey revealed that little skate are abundant throughout Georges Bank, with the highest concentrations on the U.S. side of the Bank (Figure 2-75). Approximately 60% of sets in the survey contain little skate, while the area of occupancy of this species has been stable. In this broad geographic range, little skate are most common at depths less than 111 m, but have been reported at depths down to 384 m (Scott and Scott, 1998; McEachern, 2002). Winter and little skate are sympatric over most of their ranges and are often difficult to distinguish, especially when immature.

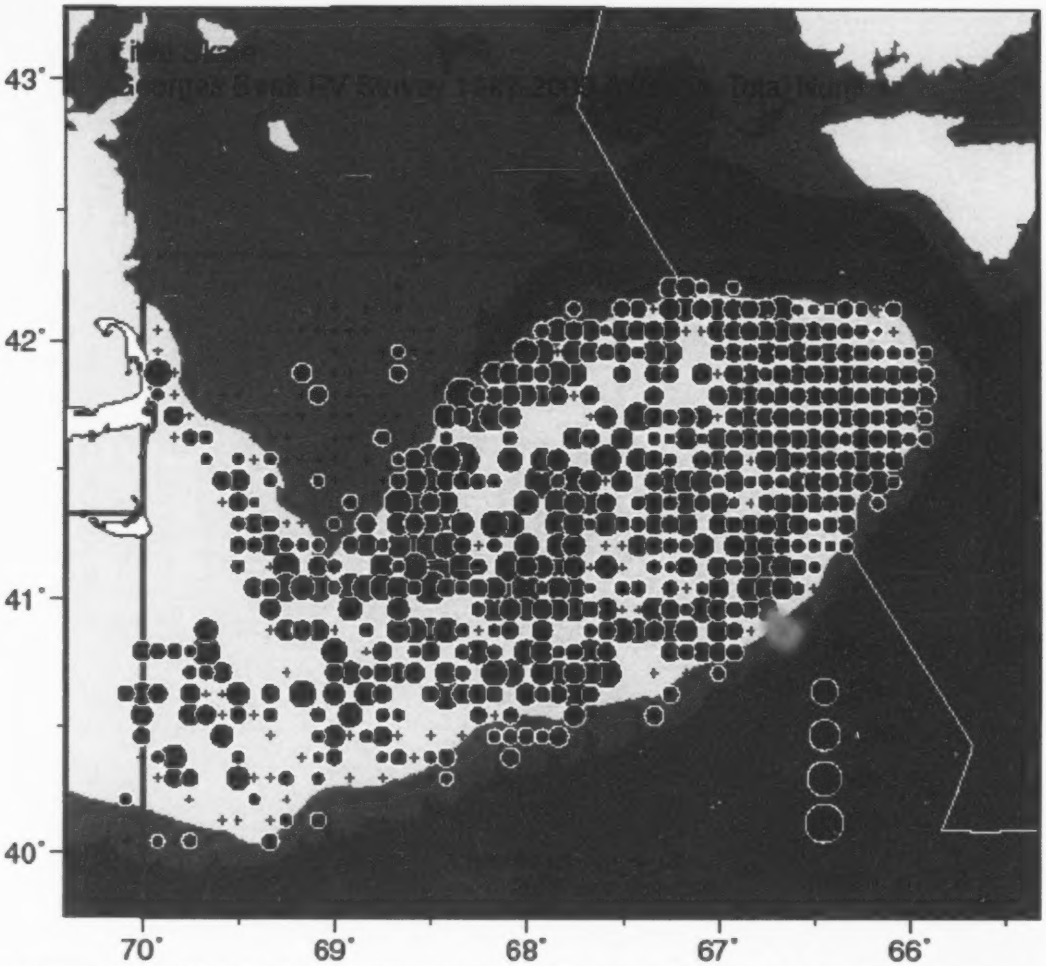


Figure 2-75. Distribution of little skate on Georges Bank from the DFO Georges Bank RV survey.

Invertebrates, such as decapod crustaceans and amphipods, followed by polychaetes, are the most important prey items of little skate. Isopods, bivalves, and fish are of minor importance. Fish that are eaten include sand lance, alewives, herring, cunners, and silver hake (Packer et al., 2003b). In general, little skate prey on infaunal species, while winter skate eat primarily epifaunal species.

The population biomass of Eastern Georges Bank little skate, as calculated from the Canadian RV survey, has fluctuated between 700-2300 t from 1987-2009, without trend (Figure 2-76). Abundance (number per tow) has also fluctuated without trend since the beginning of the series. The spring and fall U.S. RV surveys that survey from the Gulf of Maine to the Mid-Atlantic Bight were examined from 1975-2006 to put the DFO Georges Bank RV data into context. In general, abundance increased from the beginning of the spring survey to a peak in 2000. Abundance subsequently declined to near the average estimate. The fall survey estimates have increased slightly over the entire survey series (NEFSC, 2007).

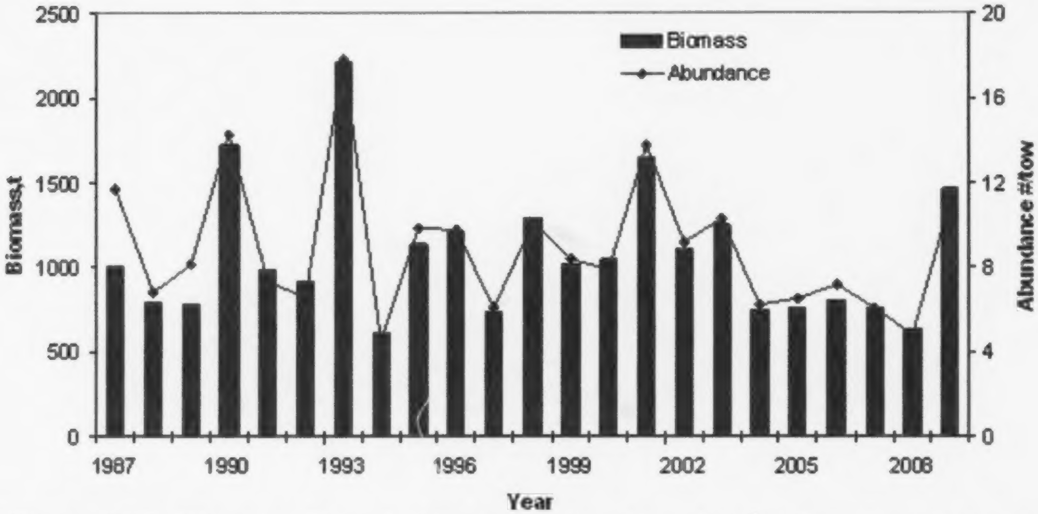


Figure 2-76. Biomass (t) and abundance (numbers tow^{-1}) of eastern Georges Bank little skate.

Population Structure Relative to Moratorium Area

The Canadian and U.S. RV seasonal surveys indicate that little skate are widespread and abundant over the Georges Bank moratorium area throughout the year (NEFSC, 2007). Given the continuous distribution of little skate, there is a high likelihood that the fish on both sides of the border constitute a single population on Georges Bank. The relationship between little skate on Georges Bank and Browns Bank is unknown although, given the depth preferences of the species and the depth of the Fundian Channel, it is unlikely that there is wide scale movement between these two banks.

Life History, Location, and Timing

Skate are oviparous, depositing a single egg within a leathery capsule (purse), which is extruded. The purse has adhesive mucus that attaches to substrate materials and helps it to maintain contact with the bottom. Fully developed egg cases have been observed in U.S. waters throughout the year, with peaks in egg deposition in the fall and winter (Packer et al., 2003b). Annual production in females that have the two peaks is in the order of 30 per year. Preliminary data from the 2010 Canadian Georges Bank RV survey indicate that both winter and little skate purses have been observed on either side of the Canada/U.S. border. This suggests that little skate 'spawn' in the Georges Bank moratorium area, but spatial and temporal details are not complete at this time. Upon hatching, the juveniles are approximately 10 cm in length.

Known Vulnerabilities

Given the benthic nature of juveniles and adults, it is possible that little skate may be vulnerable to industrial discharges. The life stage that would be most vulnerable to bottom disturbances would be skates purses due to the length of time that it takes them to hatch and their sessile nature.

Status Designation

Little skate is not listed pursuant to SARA and has not been evaluated by COSEWIC.

2.8.14.3 Thorny Skate

Distribution, Habitat, Abundance, and Predator and Prey

Thorny skate, *Amblyraja radiate,* are at the southern limit of their range on the Northeast Peak of Georges Bank and the Gulf of Maine, based on Canada and U.S. RV survey data (NEFSC, 2007). They are uncommon on the shallowest parts of the Bank (Figure 2-77). On the Northeast Peak they are primarily restricted to depths greater than 60 m. In this area, the area of occupancy has been declining since the beginning of the survey and they are now caught in approximately 10% of the survey sets.

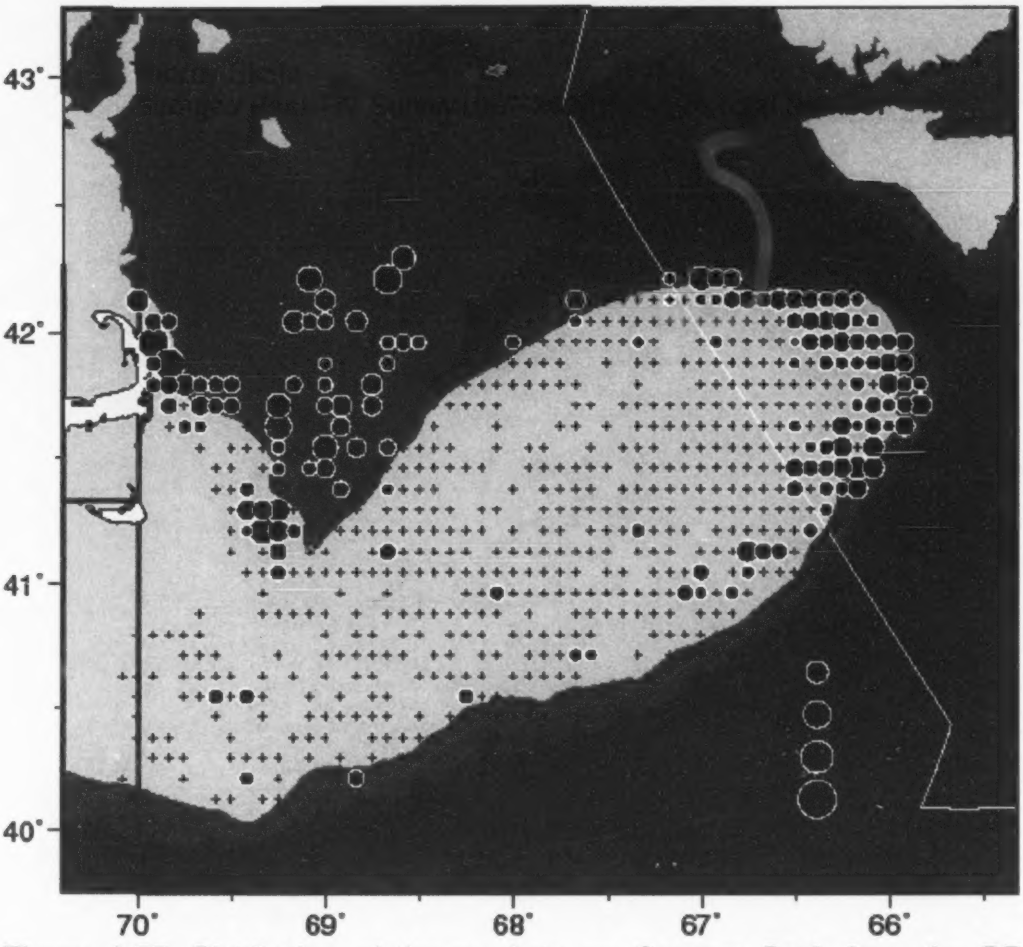


Figure 2-77. Distribution of thorny skate on Georges Bank from the DFO Georges Bank RV survey.

A wide variety of prey items have been reported to have been eaten by thorny skate. The percent composition of invertebrates such as decapod crustaceans, amphipods, and polychaetes varies with size of the predator, with fish being added as a prey item in the larger thorny skate. The fish most commonly reported as prey include sand lance, longhorn sculpins, and hagfish, although they are not a major component of the diet (Packer et al., 2003c).

The population biomass of Eastern Georges Bank thorny skate, as calculated from the DFO Georges Bank RV survey, has declined from approximately 300 t in the late 1980s to less than 100 t in recent years (Figure 2-78). The 2009 estimate is the lowest in the series. Abundance (number per tow) has also declined over the period of the survey. An examination of the spring and fall U.S. RV surveys from 1967-2006 indicates that this decline began in the early 1970s (NEFSC, 2007).

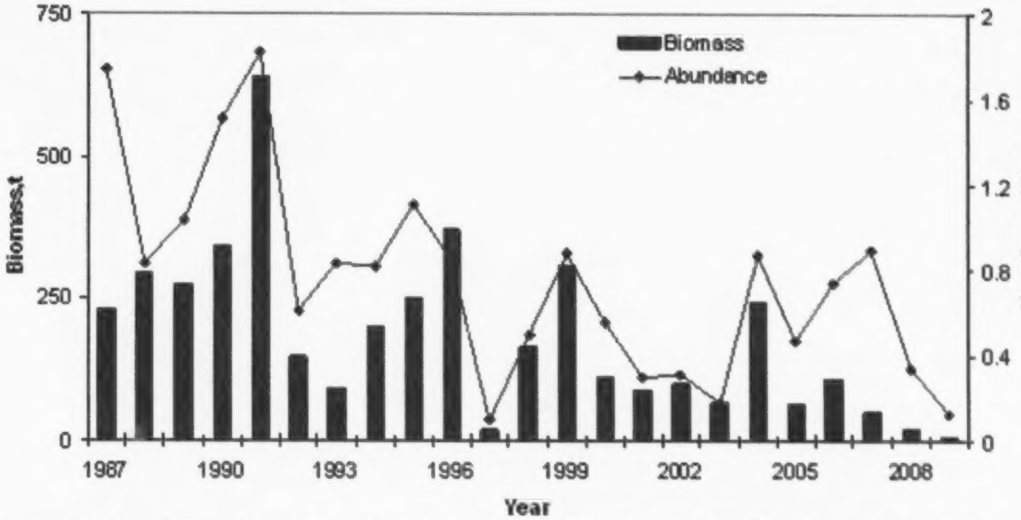


Figure 2-78 Biomass (t) and abundance (numbers tow^{-1}) of eastern Georges Bank thorny skate.

Population Structure Relative to Moratorium Area

The U.S. RV seasonal surveys indicate that thorny skate are primarily caught in the Gulf of Maine, as well as in the same area of the Northeast Peak as found in the Canadian RV survey (NEFSC, 2007). Thorny skate of the Northeast Peak are likely associated with those found in the adjacent waters of the Gulf and the Fundian Channel, but there is no data to confirm this assumption.

Life History, Location, and Timing

Mature female thorny skate have been observed with partially developed egg capsules in April, June, July, and September in the Gulf of Maine, but no such observations have been reported for Georges Bank (Packer et al., 2003c).

Known Vulnerabilities

Given the benthic nature of juveniles and adults, it is possible that thorny skate may be vulnerable to industrial discharges. The life stage that would be most vulnerable to bottom disturbances would be skates purses, due to the length of time that it takes them to hatch and their sessile nature.

Status Designation

Thorny skate is not listed pursuant to SARA and has not been evaluated by COSEWIC.

2.8.14.4 Smooth Skate

Distribution, Habitat, Abundance, and Predator and Prey

The smooth skate, *Malacoraja senta,* is a boreal species that ranges from north of the Grand Banks to South Carolina (Scott and Scott, 1988; McEachern, 2002). Although the geographic centre of distribution is the Gulf of Maine, it is more common further north and is not common south of Georges Bank. They are primarily restricted to depths greater than 90 m and are, therefore, not common on Georges Bank. On the Northeast Peak, they are more abundant on the northern edge than elsewhere (Figure 2-79).

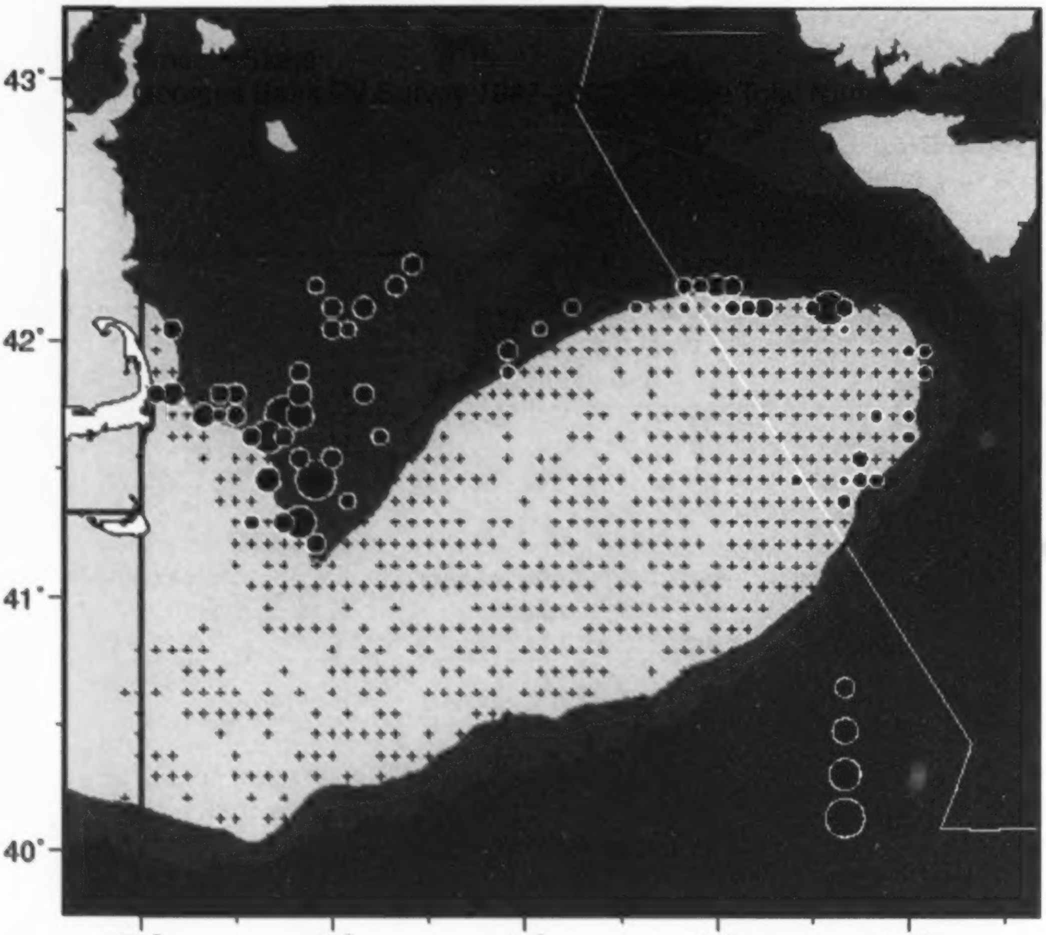


Figure 2-79. Distribution of smooth skate on Georges Bank from the DFO Georges Bank RV survey.

Smooth skate have a specialized diet that consists primarily of amphipods, euphasids, decapods, and mysids (Packer et al., 2003d). The population biomass and abundance (number per tow) of eastern Georges Bank smooth skate, as calculated from the DFO Georges Bank RV survey, is very low and has varied without trend since 1987 (Figure 2-80). An examination of the spring and fall U.S. RV surveys from the Gulf of Maine, during 1967-2006, indicates that, although there was a slight decline in abundance and biomass in the late 1960s, there has been little change in the trend since then (NEFSC, 2007).

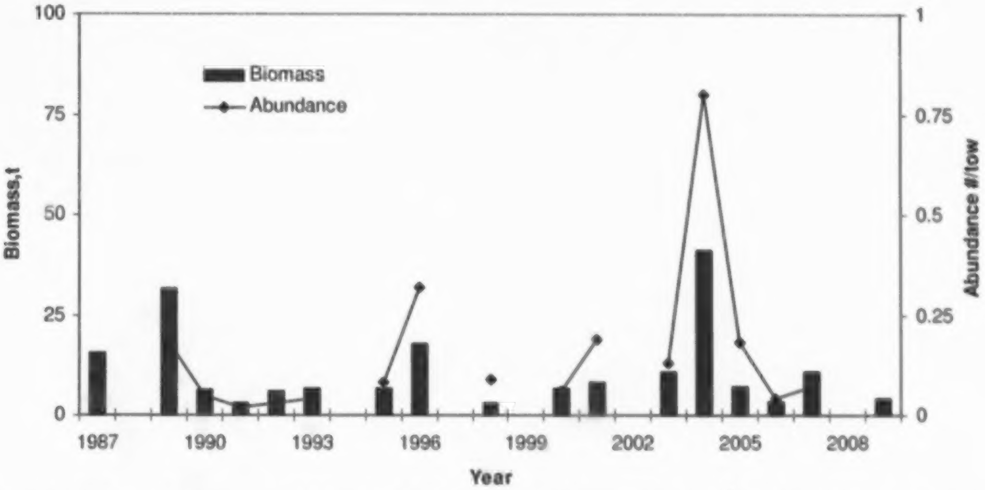


Figure 2-80. Biomass (t) and abundance (numbers tow^{-1}) of eastern Georges Bank smooth skate.

Population Structure Relative to Moratorium Area

The fish that have been observed on the Northeast Peak from the Canadian and U.S. surveys are likely from the same population as fish in the deeper waters around the Bank (NEFSC, 2007).

Life History, Location, and Timing

The life history of smooth skate is not well understood (Packer et al., 2003d).

Known Vulnerabilities

Given the benthic nature of juveniles and adults, it is possible that smooth skate may be vulnerable to operational discharges. The life stage that would be most vulnerable to bottom disturbances would be skates purses, due to the length of time that it takes them to hatch and their sessile nature.

Status Designation

Smooth skate is not listed pursuant to SARA and has not been evaluated by COSEWIC.

2.8.14.5 Barndoor Skate

Distribution, Habitat, Abundance, and Predator and Prey

Barndoor skate, *Dipturus laevis,* historically have ranged from the southern Grand Banks down to North Carolina, based on Canadian and U.S. RV survey data (Scott and Scott, 1988; McEachern, 2002). Recent analysis of Canadian RV surveys indicate the overall distribution of the species extends as far north as the Labrador Shelf up to depths of 1600 m (Gedamke et al., 2005). In recent years, they are most abundant from Georges Bank to the southern flanks of the Scotian Shelf and the Grand Banks (Simon et al., 2009). On Georges Bank, they are primarily restricted to the southern portion of the Bank on both the Canadian and U.S. sides of the international boundary (NEFSC, 2007) (Figure 2-81).

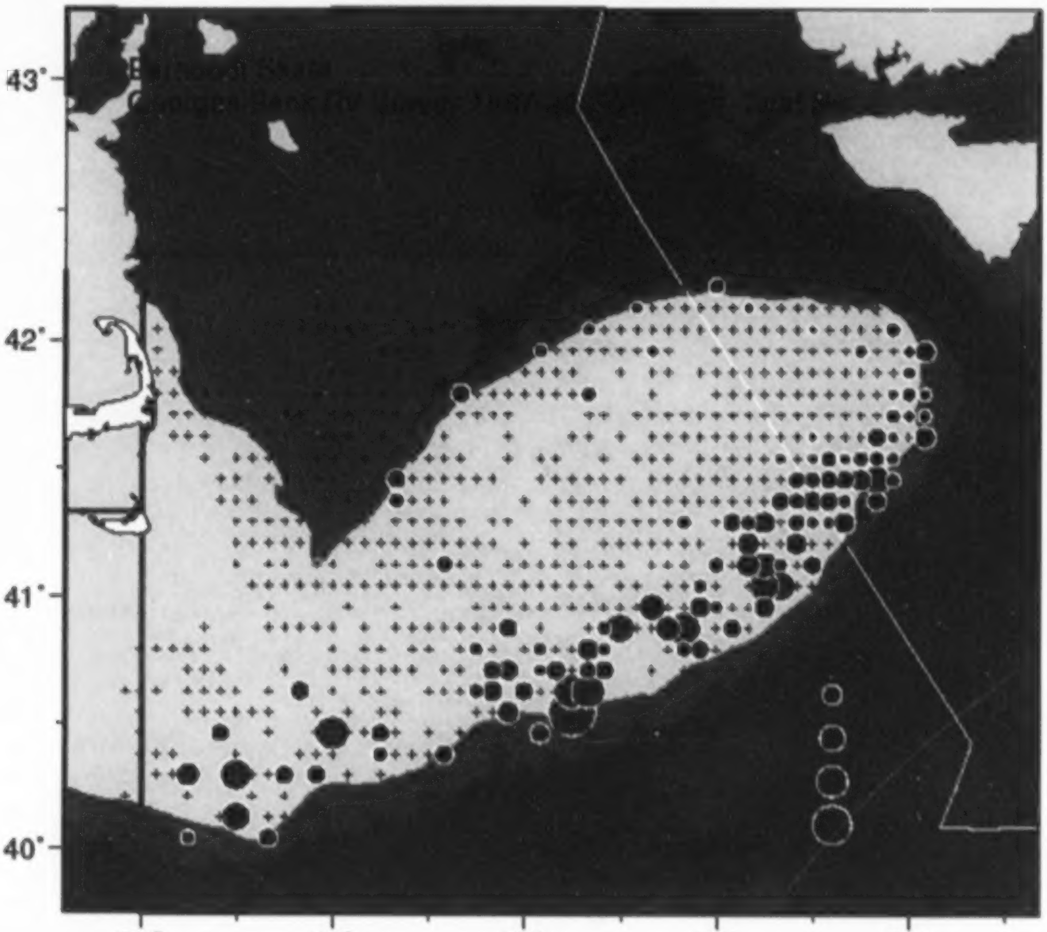


Figure 2-81. Distribution of barndoor skate on Georges Bank from the DFO Georges Bank RV survey.

Small barndoor skate (less than 70 cm in length) are predominately bottom feeders that primarily consume shrimp and crabs on Georges Bank. Larger barndoor skate consume primarily fish including sculpins, red hake, ocean pout, and herring (Packer et al., 2003e; Simon et al., 2009). The population biomass and abundance (number per tow) of eastern Georges Bank barndoor skate, as calculated from the Canadian RV survey, has varied without trend since 1987 (Figure 2-82). An examination of the spring and fall U.S. RV surveys during 1963-2006 indicates that, when the entire survey area is considered, abundance was high in the 1960s and declined to very low levels in the 1970s to mid-1990s. Abundance has subsequently increased to estimates seen in the beginning of the survey. It is important to note that barndoor skate have been observed to be particularly adept at avoiding trawl gear, thus all estimates should be considered minimum estimates (Edwards, 1968).

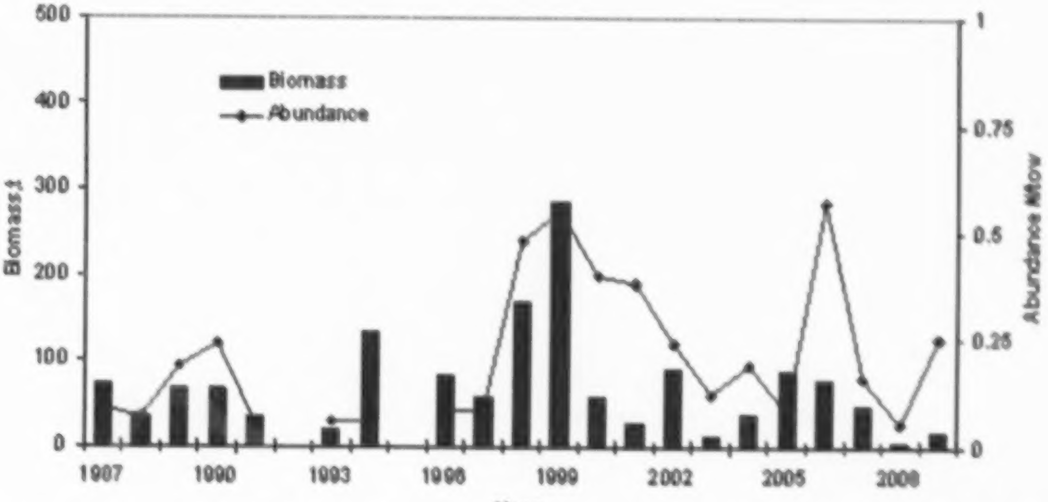


Figure 2-82. Biomass (t) and abundance (numbers tow^{-1}) of eastern Georges Bank barndoor skate.

Population Structure Relative to Moratorium Area

The U.S. RV seasonal surveys indicate some seasonal movement on the Bank, but no widescale migrations between Georges Bank and adjacent areas (NEFSC, 2007). Given the distribution of barndoor skate from the Canadian RV survey, there is a high likelihood that the fish on both sides of the border constitute a single population on Georges Bank. The relationship between barndoor skate on Georges Bank and the Scotian Shelf is unknown although, given the wide range of depths that the species has been observed, the Fundian Channel would not act as a barrier to the species.

Life History, Location, and Timing

Initial analyses on the extinction possibility of barndoor skate used life history characteristics from other skate species (Casey and Myers, 1998). A comprehensive analysis of these characteristics by Gedamke et al. (2005), from fish collected on Georges Bank, concluded that barndoor skate mature younger and grow more quickly than previously thought. Barndoor skate are 50% mature at 112 cm in length, at which time they are 6-7 years old. The Montreal Biodome reported on the growth and egg production from a barndoor skate maintained at their facility. Purses were laid throughout the year, with an incubation time of 343-494 days. Annual fecundity ranged from 70-115 (Parent et al., 2008). This estimate is much higher than had originally been estimated for the species.

Known Vulnerabilities

Given the benthic nature of juveniles and adults, it is possible that barndoor skate may be vulnerable to operational discharges. The life stage that would be most vulnerable to bottom disturbances would be skates purses due to the length of time that it takes them to hatch and their sessile nature. The location of skate purses is unknown.

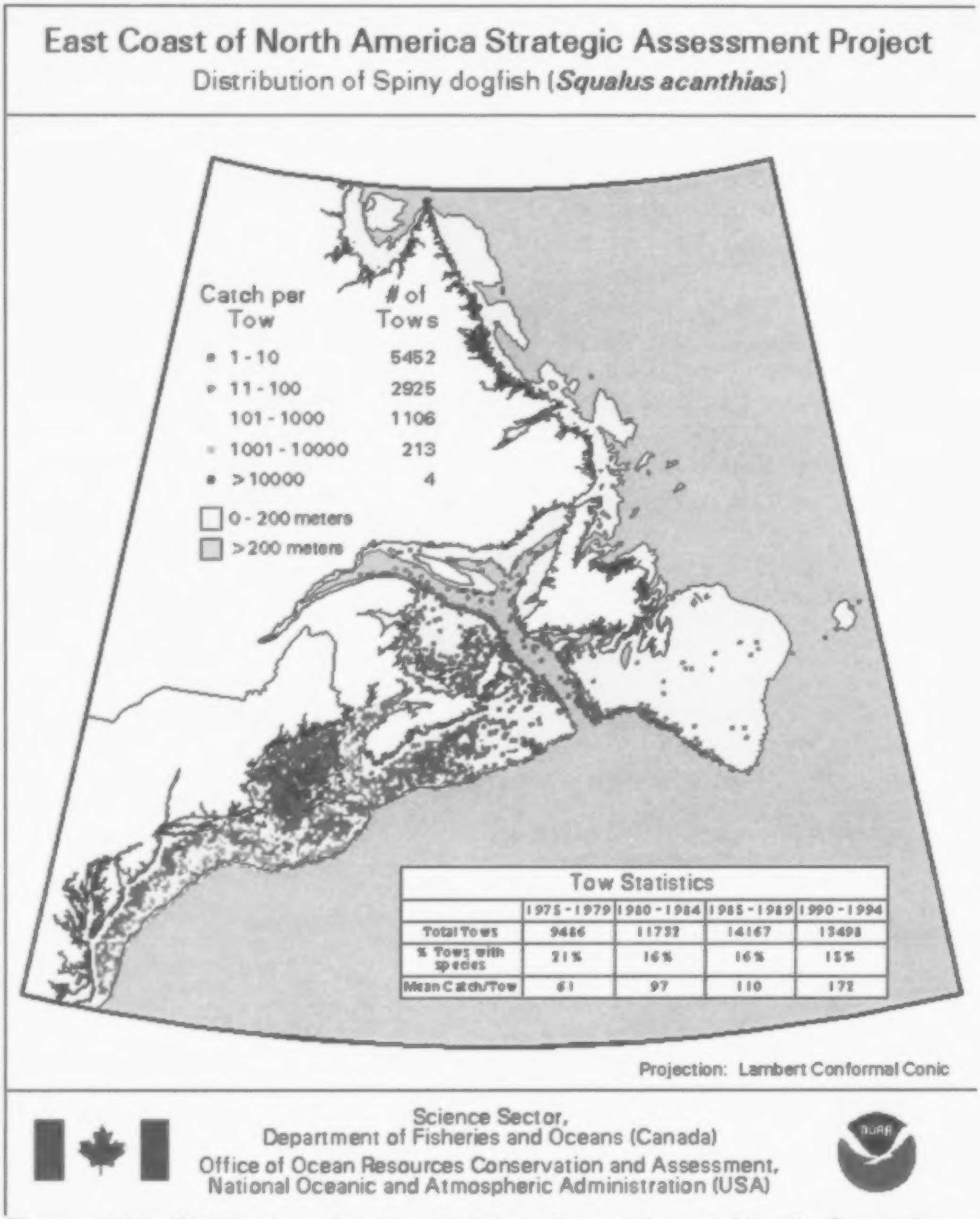
Status Designation

Barndoor skate is not listed pursuant to SARA and has not been evaluated by COSEWIC. The International Union for the Conservation of Nature (IUCN), however, concluded in 1994 that barndoor skate should be listed as 'vulnerable'. The U.S. National Marine Fisheries Service conducted an evaluation of the species in 1999 and concluded that there was no evidence that they were in danger of extinction or likely to become so in the near future. Nevertheless the IUCN reevaluated the status of the species in 2003 and listed the species as 'endangered' due, in part, to its life history characteristics.

2.8.15 Spiny Dogfish

Distribution, Habitat, Abundance, and Predator and Prey

Spiny dogfish, *Squalus acanthias,* is a small squaloid shark common both on the bottom and in the water column of coastal temperate oceans around the world. In the northwest Atlantic, dogfish are most abundant from southern Newfoundland to North Carolina, although they can be found further north and south (Figure 2-83). In the northwest Atlantic, there appears to be be both migratory and resident dogfish populations. For the most part, dogfish tagged in the Canadian and U.S. waters have remained there. There is some movement, however, between Canadian and U.S. waters, with the Gulf of Maine region being the primary mixing ground, supporting the view that there are several non-independent stock components. The primary factor affecting the seasonal inshore-offshore movements and coastal migrations may be water temperature (DFO, 2007a).



East Coast of North America Strategic Assessment Project

Distribution of Spiny dogfish (***Squalus acanthias***)

Catch per Tow
# of Tows
● 1-10 5452
● 11-100 2925
101-1000 1106
● 1001-10000 213
● >10000 4
☐ 0-200 meters
▨ >200 meters

Tow Statistics

	1975-1979	1980-1984	1985-1989	1990-1994
Total Tows	9486	11732	14167	13498
% Tows with species	21%	16%	16%	15%
Mean Catch/Tow	61	97	110	172

Projection: Lambert Conformal Conic

Science Sector,
Department of Fisheries and Oceans (Canada)
Office of Ocean Resources Conservation and Assessment,
National Oceanic and Atmospheric Administration (USA)

Figure 2-83. Distribution of spiny dogfish in the northwest Atlantic Ocean based on research trawl surveys conducted by DFO and NOAA from 1975-1994 (Brown et al., 1996).

The spiny dogfish is an opportunistic feeder eating whatever prey is abundant. In general, the diet is comprised of small fishes such as capelin, cod, haddock, hake, herring, mackerel, and sand lance. They also eat invertebrates such as krill, crabs, polychaete worms, jellyfish, ctenophores, amphipods, squid, and octopus (Zwanenburg et al., 2006). There are currently no estimates of the absolute population abundance of spiny dogfish in the northwest Atlantic. Minimum estimates, however, indicate that the population increased from the early-1980s to the early-1990s to approximately 500,000 t, and then declined to the present value of approximately 300,000 t (DFO, 2007b).

Population Structure Relative to Moratorium Area

The Gulf of Maine and Georges Bank has been suggested as an important mating ground for spiny dogfish sharks in the northwest Atlantic. Sexually mature and pregnant females were distributed throughout the waters of southwest Nova Scotia during the summer and fall and moved offshore to deeper waters in the winter. Pupping grounds have not been observed in Canadian waters, however, large aggregrations of mature females occur in deep warm waters off the edge of the contential shelf and in deep basins of the central shelf throughout their range. This suggests that pupping occurs in these deep offshore areas during the winter (DFO, 2007b).

Life History, Location, and Timing

This species is a relatively unproductive shark with a generation time of approximately 30 years. Males mature at 10 years while females mature at 16 years. They are thought to mate in winter, although the mating grounds in the North Atlantic remain unknown. After an extended gestation period of 18-22 months, an average of 5-6 pups are born during the winter months in the warmer waters off the edge of the continental shelf and in the deep basins of the central shelf throughout their range (North Carolina or New England).

Known Vulnerabilities

Patterned pulses of sound can act as attractants to sharks. Several field studies have shown that sharks in both coastal and pelagic habitats are attracted to sites where broadband, low-frequency pulses in the range of 25-200 Hz are broadcast (Edds-Walton and Finneran, 2006). The pulsed sounds are most attractive when pulse presentation is intermittent and not continuous. These low-frequency pulses are similar to the sounds produced by struggling prey or actively feeding fish. This and other studies listed in Myrberg (2001) indicate that any high-level, low-frequency pulses could attract sharks from hundreds of metres away.

The resulting redistribution of sharks could alter normal behavioral patterns, as well as cause an increase in aggressive interactions between and/or among sharks that normally would not interact. While there is evidence that habituation would occur if the pulsed sound were on-going for several days, there is also the possibility that the hunting ability of the sharks in the area may be impaired if the normal sounds of struggling or feeding prey are masked by low-frequency pulsed signals. In addition, the long gestation period, late age of sexual maturation, and slow growth rate for spiny dogfish makes the species susceptible to increased mortality from all sources including human activities.

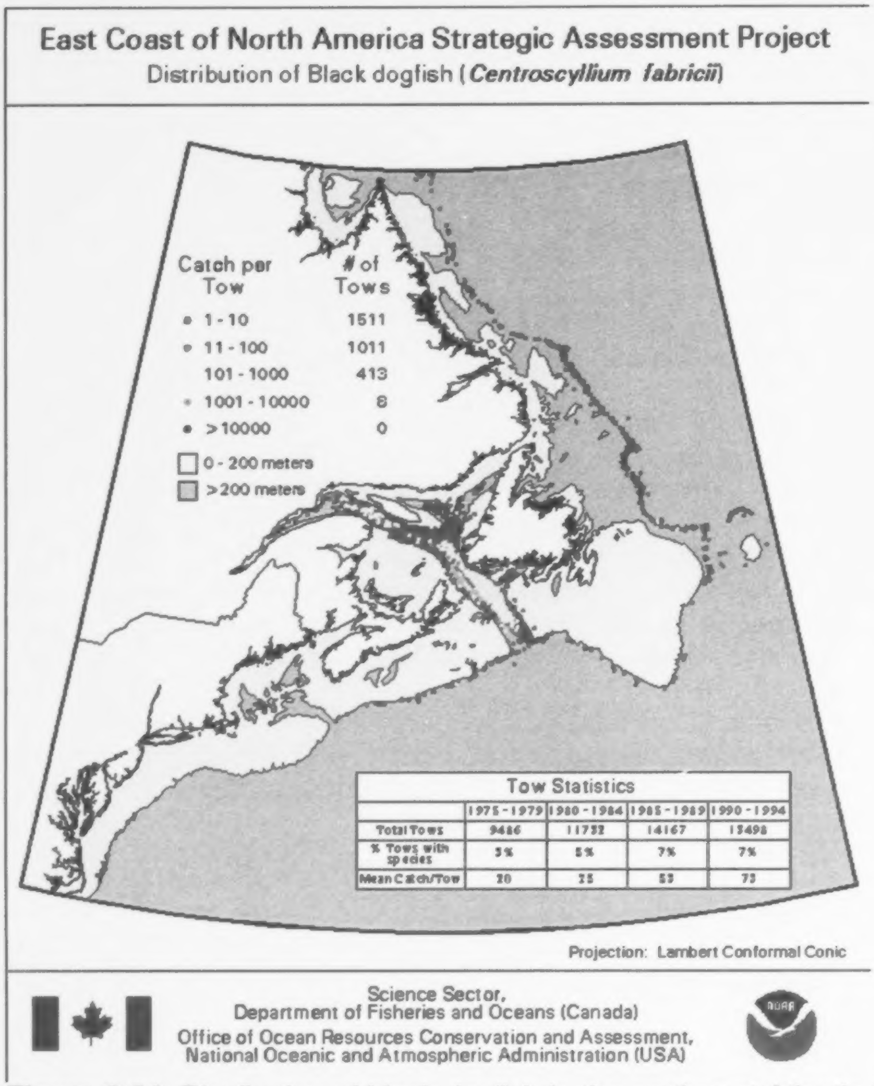
Status Designation

Spiny dogfish is not listed pursuant to SARA, although COSEWIC designated the species as 'special concern' in April 2010.

2.8.16 Black Dogfish

Distribution, Habitat, Abundance, and Predator and Prey

The black dogfish, *Centroscyllium fabricii,* is a small, bottom-dwelling shark that sometimes forms large schools, which are possibly segregated by sex and size. It is a deepwater species found in temperate to boreal waters over the outer continental shelves and slopes of the North Atlantic Ocean. In the northwestern Atlantic it ranges from Greenland to North Carolina and possibly Florida (Figure 2-84). This species typically occurs at shallower depths in the northern part of its range (Kiraly et al., 2003). The diet of the back dogfish consists primarily of crustaceans, squids, cephalopods, jellyfish, and bony fishes (Kiraly et al., 2003). Information regarding its abundance remains unknown.


East Coast of North America Strategic Assessment Project
Distribution of Black dogfish (*Centroscyllium fabricii*)
Catch per Tow
# of Tows
● 1-10 1511
● 11-100 1011
101-1000 413
● 1001-10000 8
● >10000 0
☐ 0-200 meters
▨ >200 meters
Projection: Lambert Conformal Conic
Science Sector,
Department of Fisheries and Oceans (Canada)
Office of Ocean Resources Conservation and Assessment,
National Oceanic and Atmospheric Administration (USA)
NOAA

Tow Statistics

	1975-1979	1980-1984	1985-1989	1990-1994
Total Tows	9486	11732	14167	13498
% Tows with species	3%	5%	7%	7%
Mean Catch/Tow	20	25	53	73

Figure 2-84. Distribution of black dogfish in the northwest Atlantic Ocean based on research trawl surveys conducted by DFO and NOAA from 1975-1994 (Brown et al., 1996).

Population Structure Relative to Moratorium Area

Information regarding the population structure and movement of black dogfish remains unknown.

Life History, Location, and Timing

There is little information on the reproductive biology of the this species. Black dogfish sharks reproduce throughtout the year without a well defined breeding or pupping season. The litter size ranges from 4-40 pups, with a mean of 16 (Yano, 1995).

Known Vulnerabilities

Patterned pulses of sound can act as attractants to sharks. Several field studies have shown that sharks in both coastal and pelagic habitats are attracted to sites where broadband, low-frequency pulses in the range of 25-200 Hz are broadcast (Edds-Walton and Finneran, 2006). The pulsed sounds are most attractive when pulse presentation is intermittent and not continuous. These low-frequency pulses are similar to the sounds produced by struggling prey or actively feeding fish. This and other studies listed in Myrberg (2001) indicate that any high-level, low-frequency pulses could attract sharks from hundreds of metres away.

The resulting redistribution of sharks could alter normal behavioral patterns, as well as cause an increase in aggressive interactions between and/or among sharks that normally would not interact. While there is evidence that habituation would occur if the pulsed sound were on-going for several days, there is also the possibility that the hunting ability of the sharks in the area may be impaired if the normal sounds of struggling or feeding prey are masked by low-frequency pulsed signals.

Status Designation

Black dogfish is not listed pursuant to SARA and has not been evaluated by COSEWIC.

2.8.17 Large Pelagics

The shelf and slope waters of Georges Bank provide important foraging habitat for several large pelagic species (i.e. sharks, swordfish, and tunas) during their seasonal feeding migrations along the edge of the continental shelf. Six species of large sharks are regularly found on or around Georges Bank. These include porbeagle, thresher, basking, shortfin mako, blue, and smooth hammerhead sharks. White sharks are rare in Canadian waters, however, as it has been designated by COSEWIC as endangered, information on white shark is included below. Similarly, immature swordfish and bluefin tuna are attracted to Georges Bank during the summer to take advantage of the plentiful prey.

2.8.17.1 Swordfish

Distribution, Habitat, Abundance, and Predator and Prey

The broadbill swordfish, *Xiphias gladius*, is a pelagic species that is found in tropical and temperate seas throughout the world. They are distributed widely in the Atlantic Ocean and Mediterranean Sea from Newfoundland to Argentina in the western Atlantic. Swordfish migrate into Canadian waters in the summer as part of their annual seasonal movement, subsequent to spawning in subtropical and tropical locations from January-March (Figure 2-85). Swordfish swim throughout the water column and are known to move over a large depth range. While in Canadian waters, swordfish exhibit regular diving behaviour during the night followed by a period of daytime basking, which is thought to be a required warm-up period following extended periods of feeding in deeper, relatively cold waters (Beckett, 1972).

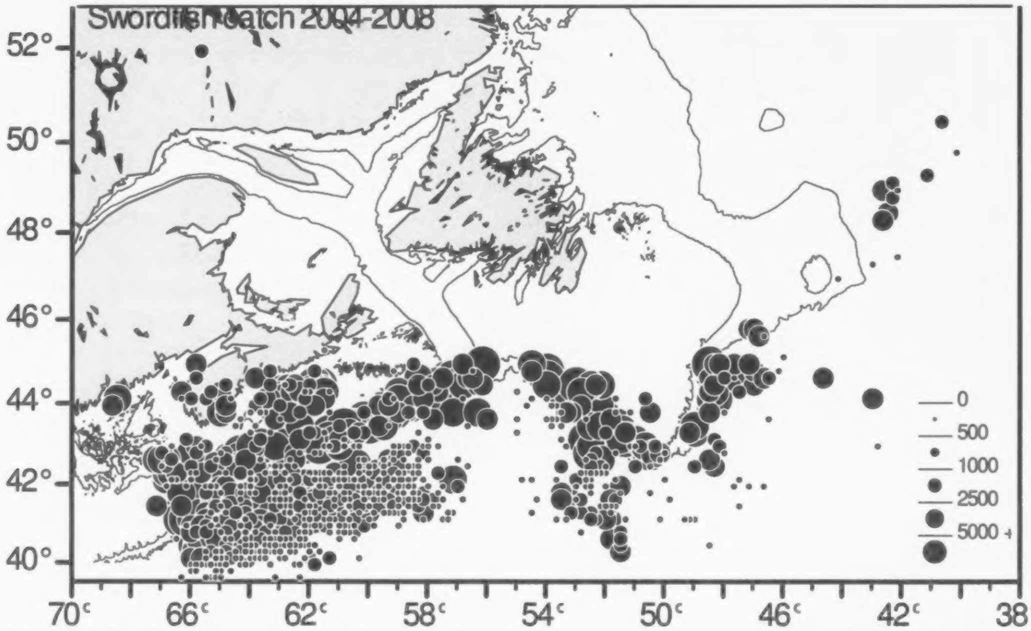
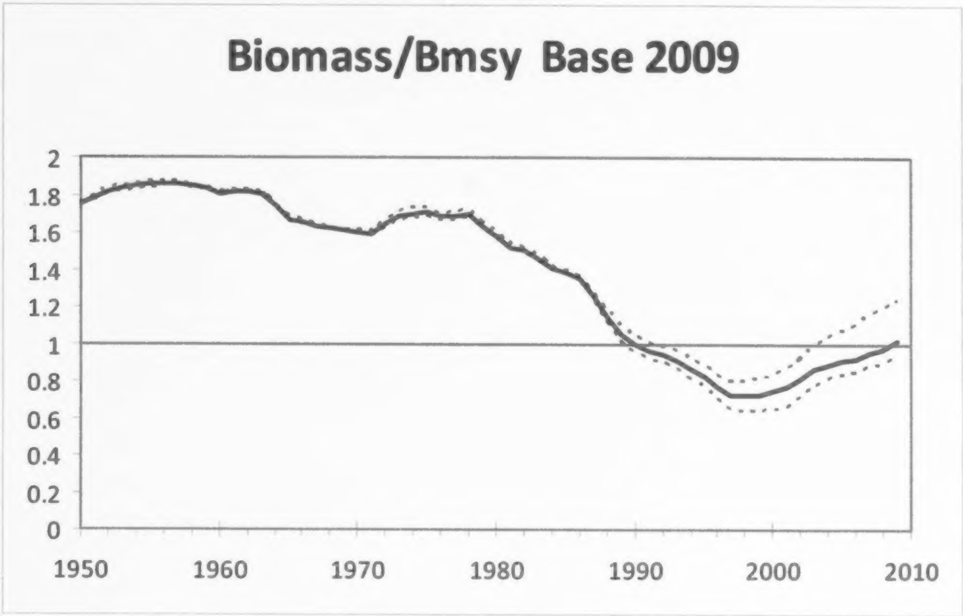


Figure 2-85. Distribution of Canadian longline catches of swordfish from 2004-2008.

Swordfish feed throughout the water column on a wide variety of prey, including groundfish, pelagic fish, and invertebrates. Stomach content analyses demonstrate that, on Georges Bank, swordfish experience high feeding success and forage on shortfin squid, barracudina, lantern fish, and silver hake (S. Smith, unpublished data). The Northeast Peak of Georges Bank is an important seasonal feeding area for Atlantic swordfish.

In 1999, the International Commission for the Conservation of Atlantic Tunas (ICCAT) established a rebuilding program for the over-exploited North Atlantic swordfish stock, with the intent of achieving appropriate stock and catch levels in 10 years (ICCAT, 2000). Due, in part, to good recruitment and low catch levels in recent years, the North Atlantic swordfish stock is considered rebuilt at the 2009 stock assessment. The estimated relative biomass trend shows a consistent increase since 2000 (Figure 2-86). The relative trend in fishing mortality demonstrates that the level of fishing peaked in 1995, followed by a decrease until 2002. There has been a small increase during the 2003-2005 period, with a downward trend since that time (ICCAT, 2009a).



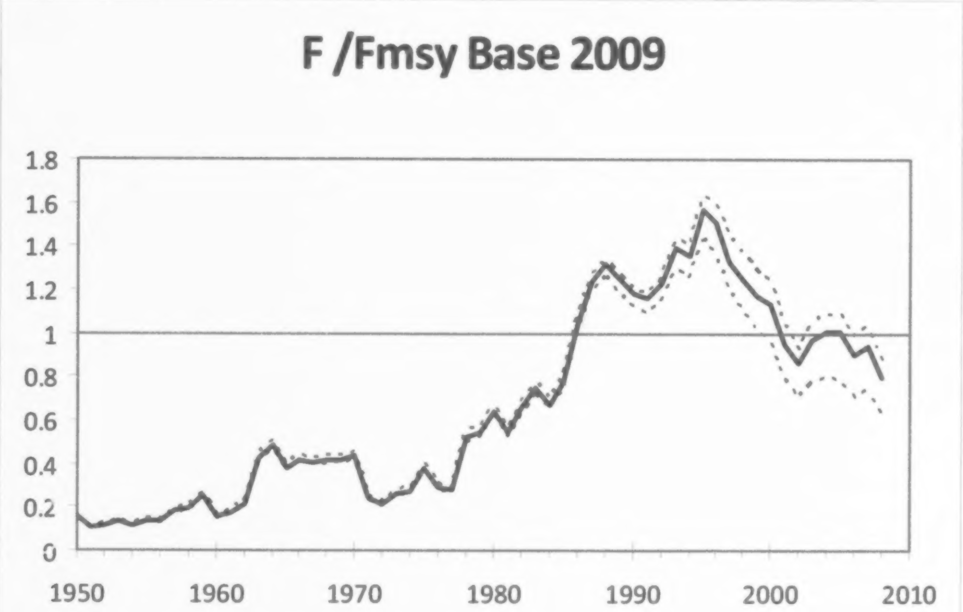


Figure 2-86. Relative biomass (top) and relative fishing mortality (bottom) trends for North Atlantic swordfish. The solid lines represent point estimates and broken lines represent estimated 80% bias corrected confidence intervals.

Population Structure Relative to Moratorium Area

Swordfish in the Atlantic Ocean are managed by ICCAT as three separate stocks: the North and South Atlantic stocks are separated at 5°N latitude, as well as the Mediterranean stock. A recent workshop on stock structure (ICCAT, 2007) supported the division, and concluded that the assumptions concerning stock structure and management units were supported by swordfish genetic information presented at that time.

The Northeast Peak of Georges Bank is an important seasonal feeding area for Atlantic swordfish. Swordfish on Georges Bank tagged with pop-up satellite archival tags revealed a consistent pattern of movement, with individuals occupying waters north of 40°N from June-October, before migrating south to the Caribbean Sea where they remained until April (Neilson et al., 2009). The tagged fish consistently returned to Georges Bank the following June, providing strong evidence of precise homing to the summer foraging grounds.

Life History, Location, and Timing

Spawning in the Atlantic Ocean is believed to occur throughout the year at locations in a geographic band extending from 34°N (off the southeast coast of the U.S.) to 35°S latitude (off southeast Brazil) (Neilson et al., 2007).

Known Vulnerabilities

Georges Bank is an established seasonal foraging area for swordfish, and there is strong evidence of annual homing behaviour. Activities that may disrupt the behaviour of large schools of prey species may cause swordfish to leave the Georges Bank area in search of alternate foraging habitat.

Status Designation

Swordfish is not listed pursuant to SARA and has not been evaluated by COSEWIC.

2.8.17.2 Bluefin Tuna

Distribution, Habitat, Abundance, and Predator and Prey

The Atlantic bluefin tuna, *Thunnus thynnus*, is a pelagic species distributed throughout the entire North Atlantic and its adjacent seas, primarily the Mediterranean Sea. It occupies the surface and subsurface waters of coastal and open sea areas between the surface and 200 m water depth. Bluefin tuna can maintain a broad range of temperatures, while preserving stable internal body temperatures. They frequently dive to great depths. They are known to form large schools and are highly migratory. Bluefin tuna migrate into Canadian waters in the summer, as part of their annual seasonal movement (Figure 2-87). Bluefin tuna are opportunistic feeders and, in general, juveniles feed on crustaceans, fish, and cephalopods, while adults primarily feed on fish such as herring, anchovy, sand lance, sardine, sprat, bluefish, and mackerel.

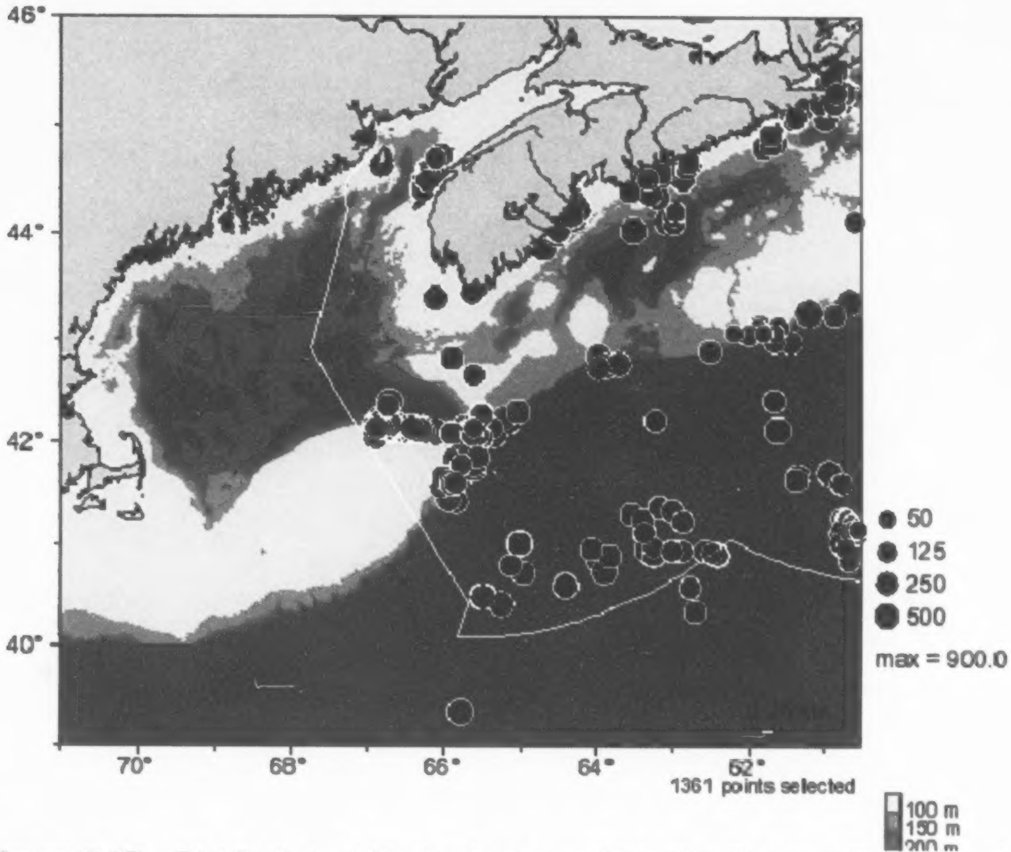


Figure 2-87. Distribution of bluefin tuna caught in the Georges Bank area in 2008.

In 1999, ICCAT considered the western Atlantic bluefin tuna stock to be over-exploited and consequently established a rebuilding plan with the intent of achieving appropriate stock and catch levels in twenty years (ICCAT, 1999). The 2009 update on stock status (ICCAT, 2009b) indicated that the Spawning Stock Biomass (SSB) of western Atlantic bluefin tuna declined steadily between the early-1970s to 1992. Since then, SSB has fluctuated between 18-27% of the 1975 level (Figure 2-88). An estimate of SSB in 2007 was 8,693 t, which is a decline of 82% of the 1970 SSB estimate of 49,482 t.

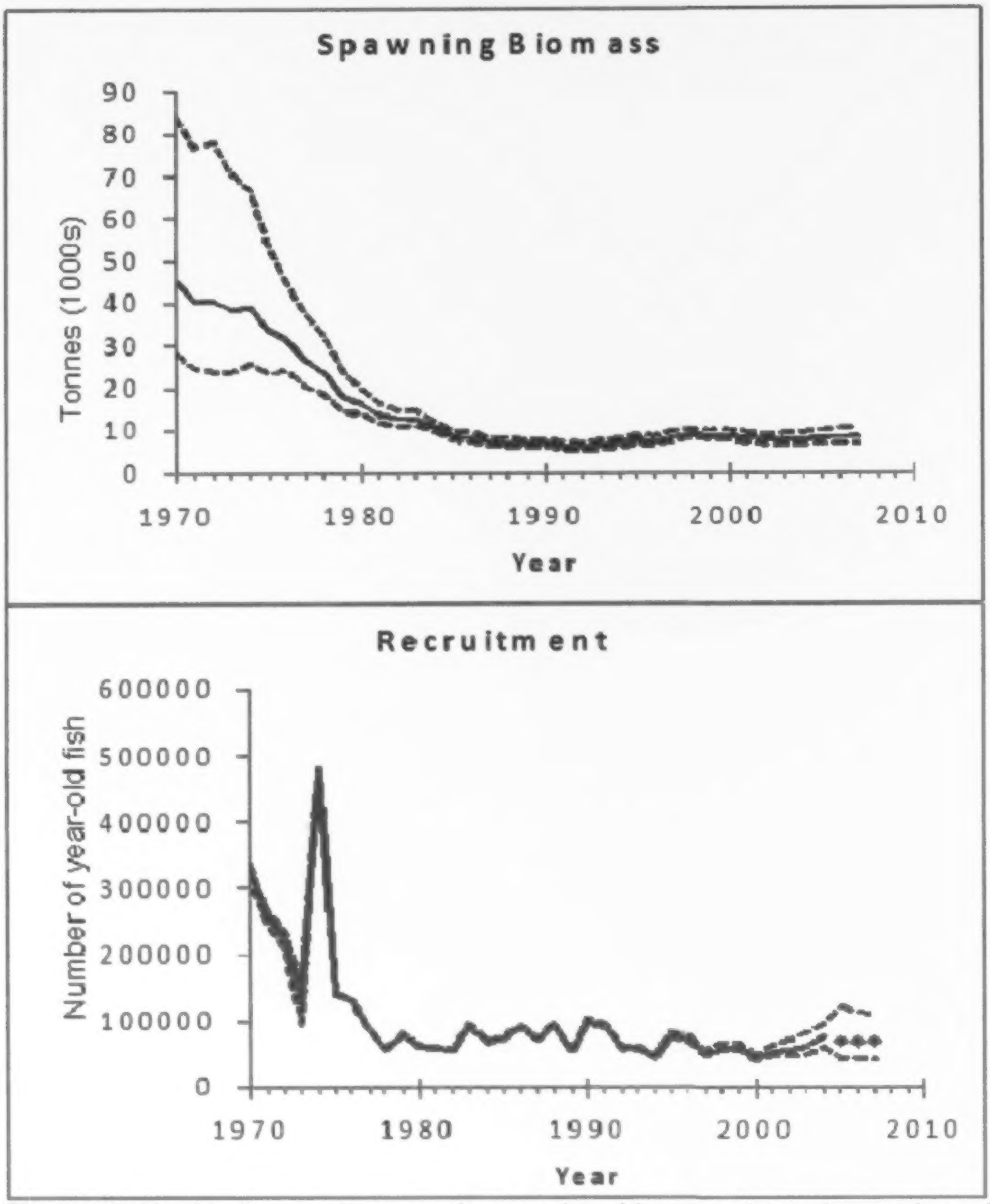


Figure 2-88. Median estimates of spawning biomass (age 8+, top) and recruitment (bottom) for western Atlantic bluefin tuna. The 80% confidence intervals are indicated with dotted lines.

The stock has experienced different levels of fishing mortality over time, depending on the size of fish targeted by various fleets. Fishing mortality on spawners (i.e. ages 8 and older) declined markedly from 2002-2007. Estimates of recruitment were very high in the early 1970s, and additional analyses involving longer catch and index series suggested that recruitment was also high during the 1960s. Since 1977, recruitment has varied from year to year without trend (Figure 2-88).

Population Structure Relative to Moratorium Area

Atlantic bluefin tuna are managed by ICCAT as two stocks: the western Atlantic and eastern Atlantic (including the Mediterranean). Bluefin tuna stock structure is complex and some mixing across the management boundary is known to occur (Lutcavage, 1999; Block et al., 2001; Block et al., 2005; Rooker et al., 2008; ICCAT, 2009b). Bluefin tuna enter Canadian waters in July and remain until November. Research on bluefin tuna migration using implantable archival tags demonstrates that Georges Bank is a high-use area by bluefin tuna, with movement onto the Bank in June-July and remaining throughout October-November (Walli et al., 2009). Golet (2010) has documented an eastern shift in position of large surface schools of bluefin tuna from the inshore Gulf of Maine to Georges Bank over a sixteen year period.

Life History, Location, and Timing

Maturity in bluefin tuna is reached at 8-12 years of age in the West Atlantic. The current understanding of bluefin tuna spawning in the western Atlantic is that it occurs in the Gulf of Mexico from April-June and, in the eastern Atlantic, spawning occurs in the Mediterranean Sea throughout the summer.

Known Vulnerabilities

Georges Bank is an established seasonal foraging area for bluefin tuna, and is a key habitat for obtaining seasonal energy requirements. Activities that may disrupt the behaviour of large schools of prey species may cause these opportunistic predators to leave the Bank area in search of alternate foraging habitat. Much of the ecology and stock structure of bluefin tuna remains unknown.

Status Designation

Bluefin tuna is not listed pursuant to SARA, although COSEWIC and the Convention on International Trade in Endangered Species (CITES) of Wild Fauna and Flora have bluefin tuna under review and have scheduled assessments for 2010.

2.8.17.3 Yellowfin Tuna

Distribution, Habitat, Abundance, and Predator and Prey

Yellowfin tuna, *Thunnus albacares*, is a pelagic species found in tropical and subtropical waters of the Atlantic, Indian, and Pacific oceans. In the western

Atlantic, they range from southern Canada to northern Argentina and, in the east, from the Netherlands to South Africa. Juvenile yellowfin tuna generally stay in coastal areas of the equatorial region, while pre-adults and adults are associated more with oceanic waters. Yellowfin tuna migrate into Canadian waters in the summer to feed (Figure 2-89).

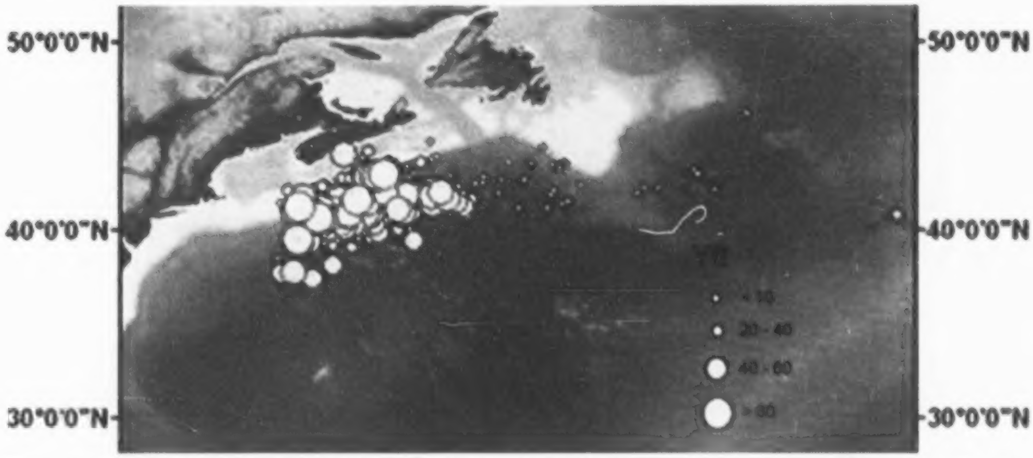


Figure 2-89. Distribution of yellowfin tuna (Yft) caught by Canadian longline in 2008.

Yellowfin tuna are opportunistic predators and feed on a broad range of prey types including fish and squid. The most recent stock assessment for Atlantic yellowfin tuna was conducted in 2008 (ICCAT, 2009c) (Figure 2-90). Although there is a fair level of uncertainty around the estimates of stock biomass and fishing mortality, they are estimated to be near levels that would support the maximum sustainable yield (MSY). Results indicate that maintaining current catch levels into the future would lead to a stock biomass somewhat above relative biomass, B_{MSY}.

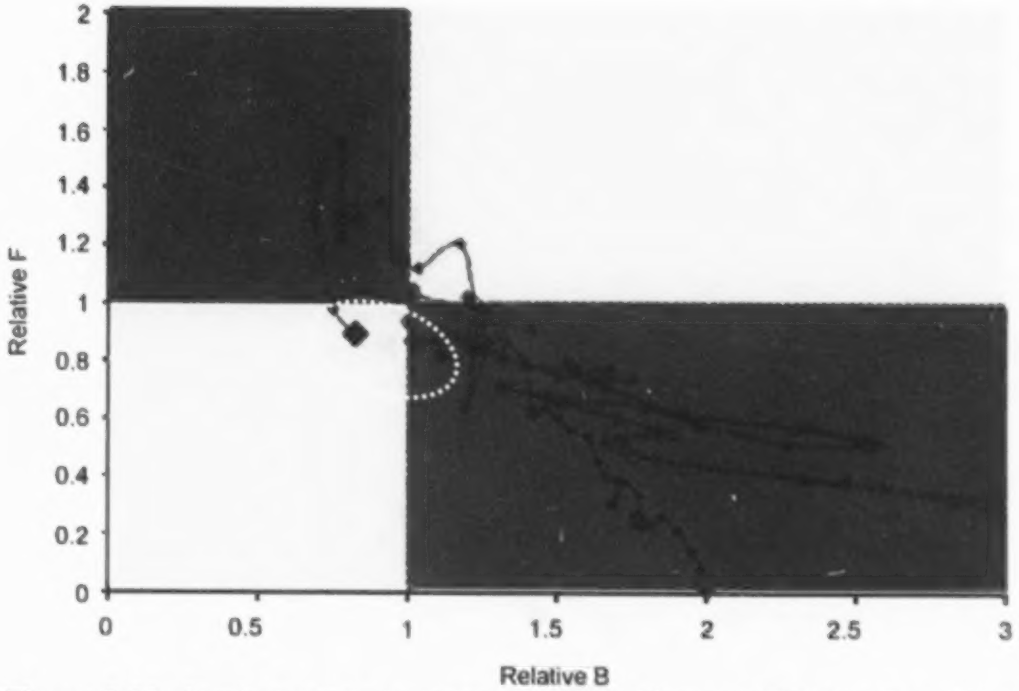


Figure 2-90. Stock status trajectories of relative biomass (Relative B, or $B/_{BMSY}$) and relative fishing mortality (Relative F, or F/F_{MSY}) from three models: ASPIC (blue line); VPArun5 (red line); and VPArun10 (green line). Current status is indicated by the large point at the end of each time series (ICCAT, 2009d).

Population Structure Relative to Moratorium Area

Yellowfin tuna are managed by ICCAT as a single Atlantic stock, based on the distribution of catches and marking studies. Transoceanic migrations are known to occur through marking studies. Yellowfin tuna enter Canadian waters in July and remain until November. They are caught in the Canadian fishery on and around the northern edge of Georges Bank.

Life History, Location, and Timing

Spawning occurs throughout the year in equatorial waters of the western and eastern Atlantic.

Known Vulnerabilities

Georges Bank is an established seasonal foraging area for many large pelagic species, including yellowfin tuna. Activities that may disrupt the behaviour of large schools of prey species may cause these opportunistic predators to leave the Georges Bank area in search of alternate foraging habitat.

Status Designation

Yellowfin tuna is not listed pursuant to SARA and has not been evaluated by COSEWIC.

2.8.17.4 Bigeye Tuna

Distribution, Habitat, Abundance, and Predator and Prey

Bigeye tuna, *Thunnus obesis*, is a pelagic species found in tropical and subtropical waters of the Atlantic, Indian, and Pacific oceans. In the western Atlantic, they range from southern Canada to northern Argentina and, in the east, from Ireland to South Africa. Young individuals typically inhabit equatorial waters, while adults migrate into northern latitudes. Bigeye tuna migrate into Canadian waters in the summer to feed (Figure 2-91).

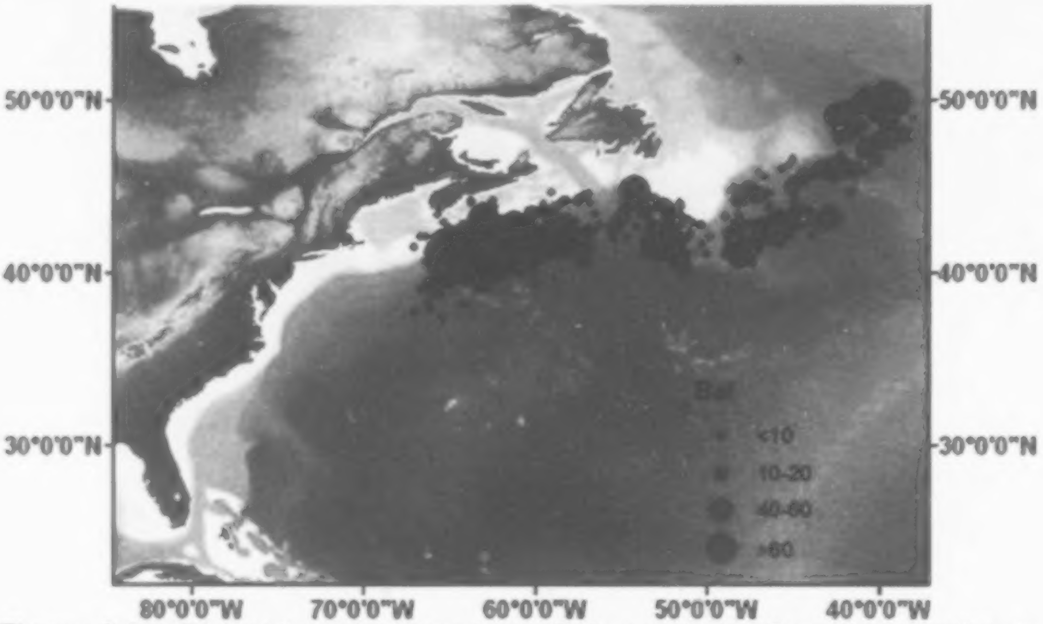


Figure 2-91. Distribution of bigeye tuna (Bet) caught by Canadian longline in 2008.

Bigeye tuna are opportunistic feeders and prey on pelagic fish, cephalopods, and euphausids. The most recent stock assessment for Atlantic bigeye tuna was conducted in 2004 (ICCAT, 2005). There was considerable uncertainty around the estimates due to lack of various types of information. Results indicated that high catches in the mid-1990s caused the stock to decline considerably (Figure 2-92). Since then, the decline leveled off as total catches decreased. The next stock assessment for bigeye tuna is scheduled for July 2010.

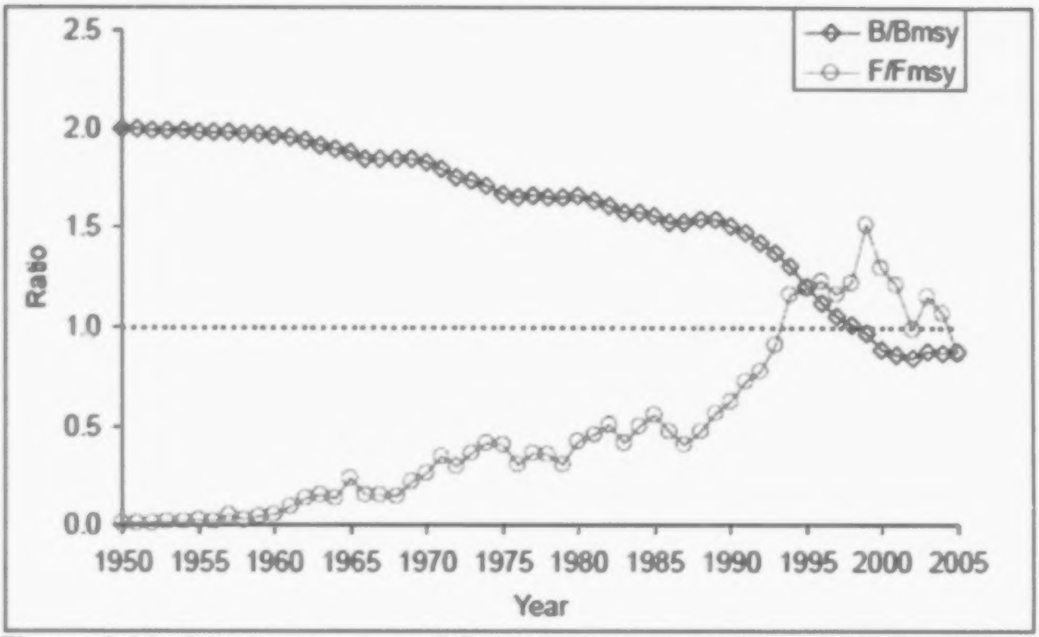


Figure 2-92. Relative biomass (B/B_{MSY}) and relative fishing mortality (F/F_{MSY}) trajectories of Atlantic bigeye tuna.

Population Structure Relative to Moratorium Area

Bigeye tuna are managed by ICCAT as a single Atlantic stock. Trans-Atlantic migrations are known through marking studies to occur from the Gulf of Guinea to the central and eastern Atlantic Ocean (Pereira, 1995). Bigeye tuna enter Canadian waters in July and remain until November. They are caught in the Canadian fishery on and around the northern edge of Georges Bank.

Life History, Location, and Timing

Spawning occurs throughout the year in equatorial waters from the coast of Brazil to the Gulf of Guinea.

Known Vulnerabilities

Georges Bank is an established seasonal foraging area for many large pelagic species, including bigeye tuna. Activities that may disrupt the behaviour of large schools of prey species may cause these opportunistic predators to leave the Georges Bank area in search of alternate foraging habitat.

Status Designation

Bigeye tuna is not listed pursuant to SARA and has not been evaluated by COSEWIC.

2.8.17.5 Albacore Tuna

Distribution, Habitat, Abundance, Predator and Prey

Albacore tuna, *Thunnus alalunga*, is a pelagic species distributed throughout the world in temperate and tropical seas. In the western Atlantic, they range from Nova Scotia to northern Argentina and, in the east, from Ireland to South Africa. Albacore tuna prefer cooler water temperatures and migrate into Canadian waters in the summer to feed (Figure 2-93).

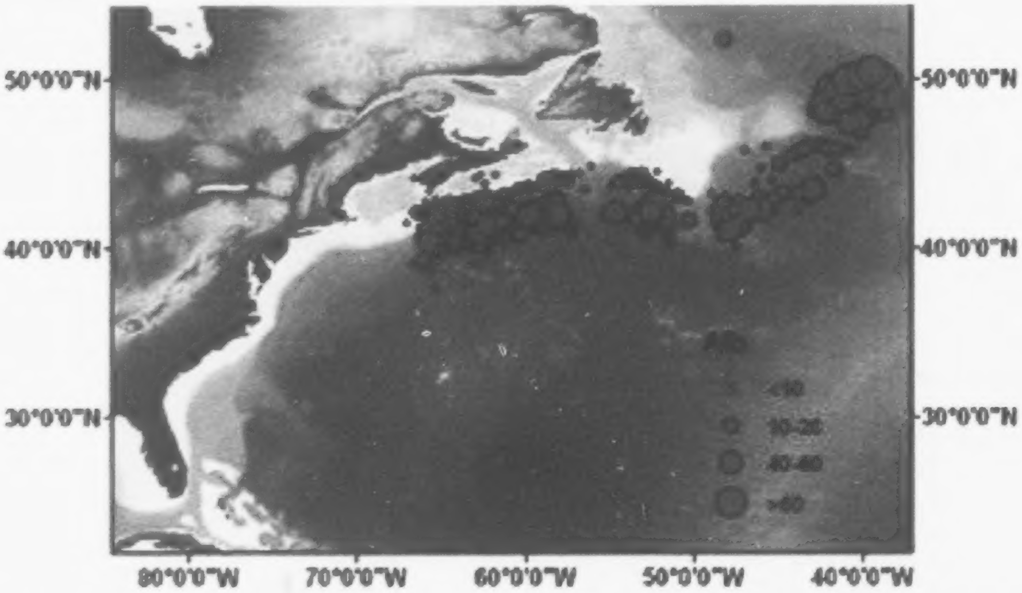


Figure 2-93. Distribution of albacore tuna (Alb) caught by Canadian longline in 2008.

Albacore opportunistically prey on schooling stocks of sardine, anchovy, mackerel, squid and, to a lesser extent, crustaceans. Spawning stock size has declined and, in 2005, was about one quarter of the peak levels estimated for the late-1940s. Estimates of recruitment to the fishery, although variable, have shown generally higher levels in the 1960s and earlier periods, with a declining trend thereafter until 2004. The most recent assessment by ICCAT of North Atlantic Albacore stock occurred in 2009 (ICCAT, 2009e). Spawning stock biomass is expected to decline from the levels estimated in 2005 over the next few years, particularly given the fact that the 2006 catch was higher than the 2005 level. The spawning stock response to different catch levels after the next few years depends upon the strength of the 2003 year-class (Figure 2-94).

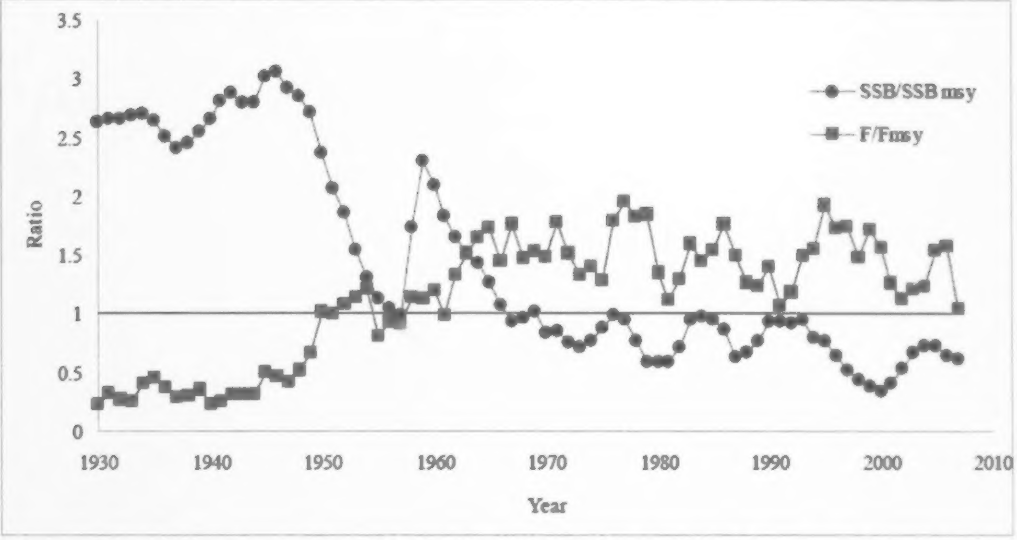


Figure 2-94. Relative biomass (B/B_{MSY}) and relative fishing mortality (F/F_{MSY}) trajectories of northern albacore.

Population Structure Relative to Moratorium Area

Albacore tuna are managed by ICCAT as three stocks: the north and south Atlantic (divided at 5˚N), as well as the Mediterranean. Although migration routes are still uncertain, Albacore tuna enter Canadian waters in July and remain until November. They are caught in the Canadian fishery on and around the northern edge of Georges Bank.

Life History, Location, and Timing

In the North Atlantic, albacore are considered mature around 90 cm in length or 5 years of age. Spawning occurs from April-September in waters offshore Venezuela, the Sargassum Sea (Le Gall, 1974; Nishikawa et al., 1985) and Gulf of Mexico (Richards, 1969; Richards, 1984).

Known Vulnerabilities

Georges Bank is an established seasonal foraging area for many large pelagic species, including albacore tuna. Activities that may disrupt the behaviour of large schools of prey species may cause these opportunistic predators to leave the Georges Bank area in search of alternate foraging habitat.

Status Designation

Albacore tuna is not listed pursuant to SARA and has not been evaluated by COSEWIC.

2.8.17.6 Porbeagle Shark

Distribution, Habitat, Abundance, and Predator and Prey

Porbeagle shark, *Lamna nasus*, is a wide-ranging coastal and oceanic shark that is the only representative of its genus in the North Atlantic. It is a cold-temperate pelagic species that occurs on both sides of the Atlantic, as well as in the south Pacific and Indian Oceans. In the western North Atlantic, the species range extends from Newfoundland to New Jersey, and possibly to South Carolina (Cassoff et al., 2007). Tagging studies indicate that only one stock resides in the northwest Atlantic, migrating between the Gulf of Maine and southern Newfoundland on an annual basis (Figure 2-95).

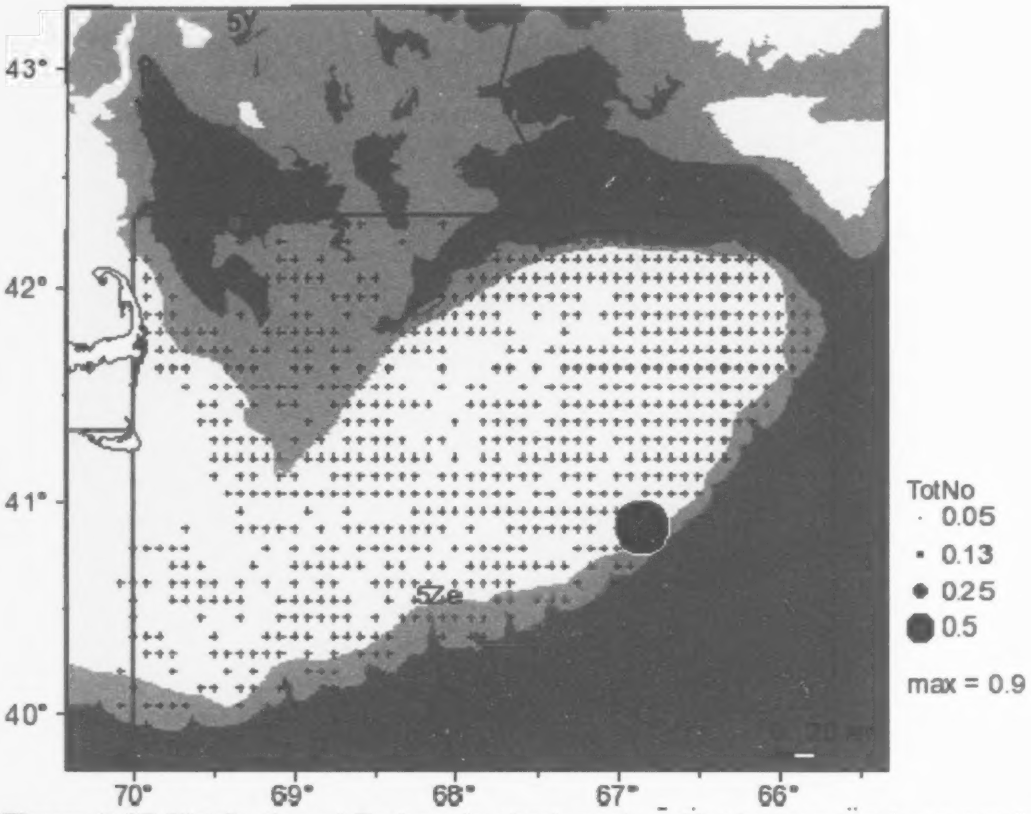


Figure 2-95 Distribution of Porbeagle shark captured by bottom trawl surveys in Georges Bank area from 1986-2008.

Porbeagle sharks move onto the Scotian Shelf in the early spring and into the Gulf of St. Lawrence and on to the Grand Banks during the summer and fall (DFO, 2002d). The primary factor affecting the distribution and habitat is thought to be temperature, with the species typically inhabiting water between 5-10°C. It is primarily an opportunistic piscivore with a diet characterized by a wide range of species. Their diet mainly consists of pelagic fishes, such as herring, lancetfish, and mackerel, however, they also eat cod, redfish, haddock, squid, and shellfish (Joyce et al., 2002).

The abundance of porbeagle shark sharply declined after the fishery of foreign longliners began in 1961, recovering only partially until Canada entered the fishery in the 1990s. Abundance declined again, but stabilized in the late 1990s after the catch quotas were reduced. In 2004, the abundance of the northwest Atlantic population was estimated at approximately 4400 t, which corresponded to 11% of the virgin population of 1961 (DFO, 2005a). Current population abundance is about 25% of the virgin population (Campana et al., 2010). Very low catch quotas and closure of the mating grounds off southern Newfoundland have allowed the population to begin to recover.

Population Structure Relative to Moratorium Area

Porbeagle sharks primarily migrate over the Georges Bank as part of their annual migration north; however, the Bank has been suggested as an important mating ground for porbeagle sharks in the northwest Atlantic. Mature female porbeagles congregate on Georges Bank in June in preparation for mating, and then disperse to other waters once mating is complete. The pupping ground location lies off the continental shelf in oceanic waters.

Life History, Location, and Timing

The porbeagle has a low fecundity, late age at sexual maturation, and low natural mortality. In the northwest Atlantic, mating occurs on the Grand Banks, south of Newfoundland, and at the mouth of the Gulf of St. Lawrence (COSEWIC, 2004). Porbeagle sharks move south and possibly into deeper water in late-fall, although their winter distribution is unknown (Zwanenburg et al., 2006). Age at maturity is approximately 8 years in males and 13 years in females. The reproductive cycle appears to last one year. After a fall mating period (September–November), females give birth to an average of 4 young in spring (April–June). The porbeagle shark life span is estimated to be between 25-46 years, with a generation time of approximately 18 years (Jensen et al., 2002).

Known Vulnerabilities

Patterned pulses of sound can act as attractants to sharks. Several field studies have shown that sharks in both coastal and pelagic habitats are attracted to sites where broadband, low-frequency pulses of 25-200 Hz are being broadcast (Edds-Walton and Finneran, 2006). The pulsed sounds are most attractive when pulse presentation is intermittent and not continuous. These low-frequency pulses are similar to the sounds produced by struggling prey or actively feeding fish. These and other studies outlined of Myrberg (2001), indicate that any high-level, low-frequency pulses could attract sharks from hundreds of metres away.

The resulting redistribution of sharks could alter normal behavioral patterns as well as cause an increase in aggressive interactions between/among sharks that normally would not interact. While there is evidence that habituation would occur if the pulsed sound persisted for days, there is also the possibility that the hunting ability of the sharks in the area could be impaired if the normal sounds of struggling or feeding prey are masked by low-frequency pulsed signals.

Status Designation

Porbeagle shark is not listed pursuant to SARA, although COSEWIC designated it as 'endangered' in May 2004.

2.8.17.7 Thresher Shark

Distribution, Habitat, Abundance, and Predator and Prey

The thresher shark, *Alopias vulpinus*, is a pelagic species that inhabits both coastal and oceanic waters worldwide. It is most common in warm temperate waters of the eastern and western Atlantic Ocean and tropical seas, but can also be found in cold temperate waters. In the northwest Atlantic Ocean, it ranges from Newfoundland to Cuba. Adults are most abundant over continental and insular shelves and slopes, while juveniles reside in coastal bays and near shore waters. This species is often associated with areas characterized by high biological productivity, such as strong frontal zones near regions of upwelling (Fowler et al., 2005).

Thresher sharks feed primarily on small, pelagic schooling fish, such as mackerel, herring, juvenile tuna, bluefish, needlefish, lancetfish, lanternfish, menhaden, and shad, as well as crustaceans, squids, octopi and, very rarely, seabirds (Fowler et al., 2005). There are few population analyses available for thresher sharks, as reliable, species-specific catch and discard data are not available. An analysis of logbook data from the pelagic longline fleets targeting swordfish and tunas in the northwest Atlantic indicates that thresher sharks have declined by more than 75% from 1986-2000 (Baum et al., 2003; Fowler et al., 2005). There is no estimate of abundance after this period.

Population Structure Relative to Moratorium Area

Information regarding the stock structure of the thresher shark in the Georges Bank area remains unknown. The common thresher is migratory, moving to higher latitudes following warm water masses. Thresher sharks are sited in Canadian waters during the summer months, occurring most frequently in Georges Bank waters from August to Septmeber.

Life History, Location, and Timing

No distinct breeding season is observed for thresher sharks and the spawning grounds for the species is unknown. The gestation period is reported to be nine months, with litters of 2-7 pups born during the spring. Thresher sharks reach maturity between 3-8 years old. They are estimated to live up to 45-50 years (Fowler et al., 2005).

Known Vulnerabilities

Patterned pulses of sound can act as attractants to sharks. Several field studies have shown that sharks in both coastal and pelagic habitats are attracted to sites where broadband, low-frequency pulses of 25-200 Hz are being broadcast (Edds-Walton and Finneran, 2006). The pulsed sounds are most attractive when pulse presentation is intermittent and not continuous. These low-frequency pulses are similar to the sounds produced by struggling prey or actively feeding fish. These and other studies outlined of Myrberg (2001), indicate that any high-level, low-frequency pulses could attract sharks from hundreds of metres away.

The resulting redistribution of sharks could alter normal behavioral patterns as well as cause an increase in aggressive interactions between/among sharks that normally would not interact. While there is evidence that habituation would occur if the pulsed sound persisted for days, there is also the possibility that the hunting ability of the sharks in the area could be impaired if the normal sounds of struggling or feeding prey are masked by low-frequency pulsed signals.

Status Designation

Thresher shark is not listed as an at-risk species pursuant to SARA and has not been evaluated by COSEWIC.

2.8.17.8 Basking Shark

Distribution, Habitat, Abundance, and Predator and Prey

Basking sharks, *Cetorhinus maximus*, are found circum-globally in temperate coastal shelf waters. Basking sharks move seasonally and are widely distributed in the North Atlantic Ocean (Gulf of St. Lawrence, Southern Newfoundland, Scotian Shelf, and Gulf of Maine) during the summer and migrate to southern U.S. waters and tropical waters in the winter. Water temperature may set a limit for the range of the basking shark, as they appear to be restricted to temperatures higher than $6^{o}C$ (DFO, 2008d).

Basking sharks are very large, slow-moving planktonic feeders with a diet that primarily consists of copepods and other zooplankton, fish eggs, and larvae. Existing fish surveys do not provide an abundance index for basking sharks. An annual index derived from surveys for right whales in the Bay of Fundy indicated a sharp increase in abundance in the 1990s followed by an equally abrupt decline by 2000. The decrease, however, was likely due to changes in distribution rather than mortality. Results of a population model indicate that the population has decreased, although sightings per unit effort indices in the U.S. show no evidence of a decline since 1979 (DFO, 2008d).

Population Structure Relative to Moratorium Area

Basking sharks often feed in the waters around Georges Bank each summer and fall. They also form mating aggregations each summer, some of which may occur in and around the Georges Bank area (DFO, 2008d).

Life History, Location, and Timing

Breeding has not been observed, but putative mating aggregations have been observed in June off the coast of Nova Scotia. Basking sharks give birth to an average of 6 pups during the summer, after a gestation period of 2-3 years (Zwanenburg et al., 2006). The winter distribution of most populations and locations used by pregnant females are unknown, although it is likely that wintering sharks occur mainly in deep shelf water (Fowler et al., 2005). Emerald Basin on the Scotian Shelf is suspected to be a mating area for the populations, although the pupping area remains unknown (DFO, 2008d).

Known Vulnerabilities

The life history characteristics of basking shark, including late maturity, long gestation period, and low fecundity, render this species particularly vulnerable. In addition, patterned pulses of sound can act as attractants to sharks. Several field studies have shown that sharks in both coastal and pelagic habitats are attracted to sites where broadband, low-frequency pulses of 25-200 Hz are being broadcast (Edds-Walton and Finneran, 2006). The pulsed sounds are most attractive when pulse presentation is intermittent and not continuous. These low-frequency pulses are similar to the sounds produced by struggling prey or actively feeding fish. These and other studies outlined of Myrberg (2001), indicate that any high-level, low-frequency pulses could attract sharks from hundreds of metres away.

The resulting redistribution of sharks could alter normal behavioral patterns as well as cause an increase in aggressive interactions between/among sharks that normally would not interact. While there is evidence that habituation would occur if the pulsed sound persisted for days, there is also the possibility that the hunting ability of the sharks in the area could be impaired if the normal sounds of struggling or feeding prey are masked by low-frequency pulsed signals.

Status Designation

Basking shark is not listed as an at-risk species pursuant to SARA, although the Atlantic population was designated as 'special concern' by COSEWIC in November 2009. In addition, basking sharks have been listed under Appendix 2 of CITES and listed by IUCN as 'vulnerable' globally and 'endangered' in the northeast Atlantic.

2.8.17.9 Shortfin Mako Shark

Distribution, Habitat, Abundance, and Predator and Prey

Shortfin mako shark, *Isurus oxyrinchus*, is circum-global in temperate and tropical waters. Individuals found in Atlantic Canada represent the northern extension of their range. The shortfin mako shark feeds mainly on bony fishes, including bluefish, mackerels, tunas, bonitos, and swordfish, but they may also eat other sharks, porpoises, other marine mammals, sea turtles, and squid (DFO, 2004b). Although there is no decline in an indicator of status for the portion of the species that is in Atlantic Canada, two separate analyses suggest recent declines in the North Atlantic as a whole (40% from 1986-2001 and 50% from 1971-2003). The shark's population abundance in the North Atlantic has declined since the 1970s, but has been relatively stable since the late 1980s with trends in median size indicating a decline in the abundance of larger shortfin makos since 1998 (DFO 2006c).

Population Structure Relative to Moratorium Area

Shortfin mako shark migrate to the Atlantic coast of Canada generally in the late summer and fall, where they are usually associated with the warm waters of the Gulf Stream. Individuals found in Atlantic Canada are considered part of a larger North Atlantic population. There does not appear to be any reason to assume that the 'Canadian Atlantic population' is demographically or genetically independent from the larger Atlantic population, so the status of the species in Atlantic Canada should reflect the status throughout the North Atlantic (DFO, 2006b).

Life History, Location, and Timing

The life cycle of shortfin mako is not completely known. Males mature at 7-9 years, while females mature at approximately 17 years. Litters of 4-25 pups are born in late-winter to mid-spring after a gestation period of approximately 15-18 months and a reproductive cycle of 3 years. The larger females give birth to more and larger pups (COSEWIC, 2006a; Fowler et al., 2005). It is hypothesized that shortfin makos in the western North Atlantic are born far offshore to protect the young from predation, mostly by other sharks (Schrey and Heist, 2003). The minimum lifespan has been estimated at 24 years, with a maximum life expectancy of up to 45 years.

Known Vulnerabilities

As a large (maximum length 4.2 m), relatively late-maturing (7-8 years) pelagic shark, shortfin mako has life history characteristics that make it particularly susceptible to increased mortality from all sources, including human activities. Bycatch from fishing activities in the North Atlantic is thought to be the most significant source of mortality for the population (Baum et al., 2003; DFO, 2006c).

Patterned pulses of sound can act as attractants to sharks. Several field studies have shown that sharks in both coastal and pelagic habitats are attracted to sites where broadband, low-frequency pulses of 25-200 Hz are being broadcast (Edds-Walton and Finneran, 2006). The pulsed sounds are most attractive when pulse presentation is intermittent and not continuous. These low-frequency pulses are similar to the sounds produced by struggling prey or actively feeding fish. These and other studies outlined of Myrberg (2001), indicate that any high-level, low-frequency pulses could attract sharks from hundreds of metres away.

The resulting redistribution of sharks could alter normal behavioral patterns as well as cause an increase in aggressive interactions between/among sharks that normally would not interact. While there is evidence that habituation would occur if the pulsed sound persisted for days, there is also the possibility that the hunting ability of the sharks in the area could be impaired if the normal sounds of struggling or feeding prey are masked by low-frequency pulsed signals.

Status Designation

The shortfin mako shark is being considered for listing pursuant to SARA. It was designated as 'threatened' by COSEWIC in April 2006.

2.8.17.10 Blue Shark

Distribution, Habitat, Abundance, and Predator and Prey

Blue shark, *Prionace glauca*, is considered to have a single highly-migratory population in the North Atlantic, of which a portion is present in Canadian waters seasonally. The blue shark is probably the most widely distributed of all shark species, occurring throughout tropical, sub-tropical, and temperate waters of the Atlantic, Pacific, and Indian Oceans. In the western Atlantic, its range extends from Newfoundland to Argentina and has been recorded from Georges and Browns Bank, along the continental shelf of Nova Scotia, the Grand Banks, and into the Gulf of St. Lawrence, in Atlantic Canada. Tagging studies indicate that the stock area may include the entire north Atlantic and that a clockwise migration occurs around this area (DFO, 1996b).

The diet of blue shark consists mainly of pelagic fish (herring, silver hake, red hake, mackerel, butterfish, tuna, and swordfish), demersal fish (cod, haddock, pollock, white hake, and sea raven), and cephalopods, particularly squid. Invertebrates (mainly pelagic crustaceans), small sharks, cetaceans (possibly carrion), and seabirds may also be eaten (DFO, 1996b).

An abundance index that is considered to best represent the portion of the population in the northwest Atlantic has declined 60% from 1986-2000. A second index shows no long-term trend for the whole population from 1971-2003. Indices of abundance in and near Canadian waters show variable trends, from no decline to 60% decline from the 1980s to early 2000s. There is evidence for a decline in mean length in longline fisheries in Canadian waters from 1986-2003 (COSEWIC, 2006b).

Population Structure Relative to Moratorium Area

Distribution and movement of this species is strongly influenced by seasonal variations in water temperature, reproductive condition, and availability of prey. Tagging studies of blue sharks have demonstrated extensive movements of blue sharks in the Atlantic, with numerous trans-Atlantic migrations that are probably accomplished by swimming slowly and utilizing the major current systems. Major oceanic migrations are associated with mating areas in the northwestern Atlantic (DFO, 2002d). From May through October, the blue shark is common offshore from the outer edge of the continental shelf, Georges Bank, to the Grand Banks, but they move south and offshore in the summer and fall (Kohler et al., 2002).

Life History, Location, and Timing

This species is a relatively productive shark (maximum age 16-20 years that mature at 4-6 years, generation time of 8 years, and 25-50 pups every two years). In the northwestern Atlantic, mating appears to be most frequent on the continental shelf from spring to early summer. After copulation, they move offshore where the sperm is stored for periods of months to years waiting for ovulation (Pratt, 1979). After fertilization, gestation is between 9-12 months. Birth has been observed over a wide seasonal range, from spring to fall, suggesting considerable variation amongst individuals.

Known Vulnerabilities

Patterned pulses of sound can act as attractants to sharks. Several field studies have shown that sharks in both coastal and pelagic habitats are attracted to sites where broadband, low-frequency pulses of 25-200 Hz are being broadcast (Edds-Walton and Finneran, 2006). The pulsed sounds are most attractive when pulse presentation is intermittent and not continuous. These low-frequency pulses are similar to the sounds produced by struggling prey or actively feeding fish. These and other studies outlined of Myrberg (2001), indicate that any high-level, low-frequency pulses could attract sharks from hundreds of metres away.

The resulting redistribution of sharks could alter normal behavioral patterns as well as cause an increase in aggressive interactions between/among sharks that normally would not interact. While there is evidence that habituation would occur if the pulsed sound persisted for days, there is also the possibility that the hunting ability of the sharks in the area could be impaired if the normal sounds of struggling or feeding prey are masked by low-frequency pulsed signals.

Status Designation

Blue shark is being considered for listing pursuant to SARA. It was designated as 'special concern' by COSEWIC in April 2006.

2.8.17.11 Smooth Hammerhead Shark

Distribution, Habitat, Abundance, and Predator and Prey

The smooth hammerhead shark, *Sphyrna zygaena,* is a migratory species that is distributed worldwide. In the western Atlantic, the smooth hammerhead shark ranges from Nova Scotia in the summer to Florida in the winter (Casper et al., 2005). The smooth hammerhead shark prefers inshore waters over continental shelves or in bays and estuaries. They may also be found in the offshore in deeper waters over the continental shelf particularly when migrating.

The smooth hammerhead shark is an active-swimming predator that feeds on bony fishes, such as herring and menhaden, rays, skates, sharks (including of its own species), cephalopods and, to a lesser extent, crustaceans such as shrimp and crabs (Casper et al., 2005). Species-specific population trends for hammerheads are rarely available because of the amalgamation of catch data and species misidentification. Analysis of logbook data indicated that hammerhead sharks (grouped data for *S. lewini, S. mokarran* and *S. zygaena*) have declined in abundance by 89% since 1986 (Baum et al., 2003).

Population Structure Relative to Moratorium Area

During summer months, smooth hammerheads sometimes form schools during migrations northward to cooler waters, which is later followed by a return south in the winter. Hammerhead sharks are not common in the Georges Bank area, although sightings have been reported on the northeast tip of the Bank.

Life History, Location, and Timing

Individuals become sexually mature at 2.3 meters in length, although the age of maturity remains unknown. During the summer months, a litter of 20-40 pups are born following a 10-11 month gestation period.

Known Vulnerabilities

Patterned pulses of sound can act as attractants to sharks. Several field studies have shown that sharks in both coastal and pelagic habitats are attracted to sites where broadband, low-frequency pulses of 25-200 Hz are being broadcast (Edds-Walton and Finneran, 2006). The pulsed sounds are most attractive when pulse presentation is intermittent and not continuous. These low-frequency pulses are similar to the sounds produced by struggling prey or actively feeding fish. These and other studies outlined of Myrberg (2001), indicate that any high-level, low-frequency pulses could attract sharks from hundreds of metres away.

The resulting redistribution of sharks could alter normal behavioral patterns as well as cause an increase in aggressive interactions between/among sharks that normally would not interact. While there is evidence that habituation would occur if the pulsed sound persisted for days, there is also the possibility that the hunting ability of the sharks in the area could be impaired if the normal sounds of struggling or feeding prey are masked by low-frequency pulsed signals.

Status Designation

Smooth hammerhead shark is not listed pursuant to SARA and has not been evaluated by COSEWIC.

2.8.17.12 White Shark

Distribution, Habitat, Abundance, and Predator and Prey

The white shark, *Carcharodon carcharias*, has a global distribution but is quite rare in the North Atlantic. It is most frequently observed in inshore waters of the western North Atlantic, Mediterranean Sea, southern Africa, Australia, New Zealand, and the eastern North Pacific. It is absent from cold polar waters, hence, Atlantic and Pacific populations in Canada are isolated from each other. This very large apex predator is rare in most parts of its range, but particularly so in Canadian waters, which represent the northern fringe of its distribution. In Atlantic Canada, there have been 32 records since 1874.

White sharks are carnivorous and primarily eat fish (including rays, tuna, and smaller sharks), dolphins, porpoises, whale carcasses, and pinnipeds such as seals, fur seals and sea lions, and sometimes sea turtles (COSEWIC, 2006c). No abundance trend information is available for white sharks in Atlantic Canada.

Numbers have been estimated to have declined by about 80% over 14 years (less than one generation) in areas of the northwest Atlantic Ocean outside of Canadian waters.

Population Structure Relative to Moratorium Area

The species is highly mobile and individuals in Atlantic Canada are likely seasonal migrants belonging to a widespread northwest Atlantic population, hence, the status of the Atlantic Canadian population is considered to be the same as that of the broader population (Baum et al., 2003; DFO, 2006d). Clustering of white shark records in Atlantic Canada during late summer months suggests that they may be correlated with the seasonal shift of the warm Gulf Stream toward the coast.

Life History, Location, and Timing

Due to the rarity of this species, knowledge of the reproduction and life history of the white shark is incomplete. White sharks are slow growing and have a relatively long life span (23-60 years). Males reach sexual maturity at an age of 8-10 years and females reach maturity at an age of 12-18 years. White sharks have a gestation period of approximately 14 months, with females giving birth to an average of 7 pups believed to occur during the spring to late summer in warm-temperate coastal waters (COSEWIC, 2006c; Fowler et al., 2005). Possible white shark pupping areas on the east coast of North America include the Mid-Atlantic Bight (COSEWIC, 2006c).

Known Vulnerabilities

Patterned pulses of sound can act as attractants to sharks. Several field studies have shown that sharks in both coastal and pelagic habitats are attracted to sites where broadband, low-frequency pulses of 25-200 Hz are being broadcast (Edds-Walton and Finneran, 2006). The pulsed sounds are most attractive when pulse presentation is intermittent and not continuous. These low-frequency pulses are similar to the sounds produced by struggling prey or actively feeding fish. These and other studies outlined of Myrberg (2001), indicate that any high-level, low-frequency pulses could attract sharks from hundreds of metres away.

The resulting redistribution of sharks could alter normal behavioral patterns as well as cause an increase in aggressive interactions between/among sharks that normally would not interact. While there is evidence that habituation would occur if the pulsed sound persisted for days, there is also the possibility that the hunting ability of the sharks in the area could be impaired if the normal sounds of struggling or feeding prey are masked by low-frequency pulsed signals.

Status Designation

Blue shark is being considered for listing pursuant to SARA. It was designated as 'endangered' by COSEWIC in April 2006.

2.9 MARINE MAMMALS

2.9.1 Cetaceans

There are approximately 23 species of cetaceans (i.e. whales and dolphins) found on or around Georges Bank, however, only a subset of these are abundant seasonally and the Canadian Georges Bank moratorium area does not represent a core distribution for any of them (CETAP, 1982; Waring et al., 2009). Although the range of each of these species is far broader than the boundaries of the Georges Bank moratorium area, the continental shelf edge and the region around the eastern end of the Bank represents a highly-utilized habitat area for cetaceans (Kenney and Winn, 1986).

Table 2-3. Seasonal abundance of cetaceans commonly found on Georges Bank. The symbols +, ++, and +++ refer to low, medium, and high abundance, respectively (adapted from Kenney et al., 1997).

Species	Season			
	Winter	Spring	Summer	Fall
N.A. Right whale		+	++	+
Fin whale	+	++	+	+
Sei whale	+	++	+	+
Minke whale		+++	+	
Humpback whale		+	+	+
Sperm whale	+	+	++	+
Northern bottlenose whale		+		
Beaked whales (*Mesoplodon spp.*)		+	+	+
Blue whale		+	+	
Pilot whales	+	+++	+++	+
Risso's dolphin		+	++	++
Bottlenose dolphin	+	++	++	+
White-sided dolphin	+	++	+++	+++
Common dolphin	+++	++	+	+++
Striped dolphin		+	++	++
Spotted dolphin			+	+
Harbour porpoise	+	+++		

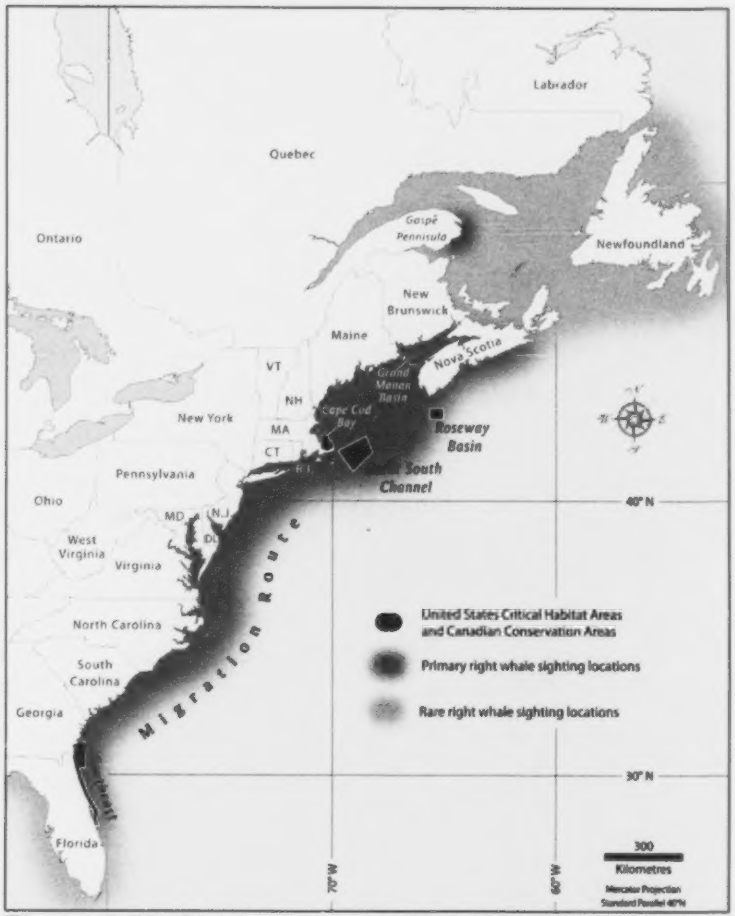
High use areas for planktivores (e.g. right whale and sei whale) are concentrated in the western Gulf of Maine and the southwestern and eastern portions of the Bank. High use areas for teuthivores (squid-eaters) (e.g. sperm whale and pilot whale) are concentrated along the edge of the shelf (Kenney and Winn, 1986).

Table 2-3 highlights the more common whales in the area, as well as their relative seasonal abundance. Katona et al. (1993), Kenney et al. (1997), and Whitehead et al. (1998) have reviewed the preferred habitat, residence time, distribution, and diet of the most common species of cetaceans found on Georges Bank, as well as the significance of the area to them. Select marine mammal species are summarized in the Appendix.

2.9.1.1 North Atlantic Right Whale

Distribution, Habitat, Abundance, and Predator and Prey

North Atlantic right whales, *Eubalaena glacialis*, herein referred to as right whales, are distributed from coastal waters of the southeastern U.S. to Newfoundland and the Gulf of St. Lawrence (Figure 2-96). Most adult females give birth in coastal waters of the southeastern U.S. during the winter months. Males and non-calving females are rarely seen in that area and their whereabouts during the winter remain largely unknown. Over-wintering aggregations, however, are known to occur in Cape Cod Bay and the central Gulf of Maine. There is a northward migration in the late winter and early spring from the calving ground, with some mother calf pairs moving along the shore. In the spring, aggregations of right whales are observed feeding and socializing in the Great South Channel, Cape Cod Bay, and Massachusetts Bay. By July, right whales can be found in the critical habitats of Grand Manan Basin in the lower Bay of Fundy and Roseway Basin on the southwestern Scotian Shelf. From October onward, a steady southward, return migration occurs, with at least part of the population passing through the Gulf of Maine.



Labrador
Quebec
Ontario
Gaspé Peninsula
Newfoundland
New Brunswick
Maine
Nova Scotia
VT
NH
Grand Manan Basin
Cape Cod Bay
New York
MA
CT
R.I.
Roseway Basin
South Channel
Pennsylvania
Ohio
MD
N.J.
DE
West Virginia
Virginia
40° N
Migration Route
North Carolina
South Carolina
Georgia
Florida
United States Critical Habitat Areas and Canadian Conservation Areas
Primary right whale sighting locations
Rare right whale sighting locations
30° N
70° W
60° W
300
Kilometres
Mercator Projection
Standard Parallel 40°N

Figure 2-96. Distribution of North Atlantic right whale in the western Atlantic. The figure has been redrawn from the 'Recovery Strategy for the North Atlantic Right Whale (Eubalaena glacialis) in Atlantic Canadian Waters' (original figure prepared by K. Lagueux, New England Aquarium).

Right whales migrate into Canadian waters to feed. Right whales in the western North Atlantic feed on a variety of organisms, but feed preferentially (and are likely dependent) on the larger, oil-rich developmental stages of the copepod *Calanus finmarchicus* (e.g. Mayo and Marx, 1990; Baumgartner et al., 2003). Species distribution likely reflects areas of high copepod populations. Other small zooplankton, such as *Pseudocalanus minutus*, *Centropages* spp., and barnacle larvae, are also occasionally eaten.

The population of right whales in the western North Atlantic was estimated to number about 322 animals (COSEWIC, 2003b). The COSEWIC (2003b) report did not present the methods used to estimate population size, however, the estimate represents the number of catalogued right whales thought to be alive in 2003. In terms of trends, the population appeared to have been declining in the 1990s (Fujiwara and Caswell, 2001), but only data through 1998 were used in those analyses. From 2002 onward, the population has exhibited relatively high calf production. By mid-decade the best estimate was approximately 350 animals (Kraus and Rolland, 2007). At present, population abundance is estimated at around 450 individuals (best estimate of 458 animals in 2009; pers comm. Right Whale Consortium).

Population Structure Relative to Moratorium Area

Right whales use Georges Bank mainly to transit from wintering areas further south to feeding areas in Canadian waters, but they also have been observed feeding on and around the Bank. In the spring, the Great South Channel (which is considered critical habitat) and the northern edge of Georges Bank are important feeding areas. During recent years, aggregations of right whales occasionally have been observed on the northern edge of the Bank into the summer months.

Life History, Location, and Timing

Female right whales give birth to a single calf in coastal waters of the southeastern U.S. between Brunswick, Georgia, and Cape Canaveral, Florida, during the winter months (Kraus et al., 1986). In 1992, the mean interval between births was 3.67 years (Knowlton et al., 1994), with a range of 2-7 years. The mean age at sexual maturity of females is not known, but the mean age when they give birth to their first calf is currently about 10 years (COSEWIC, 2003b). Right whales are found along Georges Bank in the spring, summer, and autumn months during their seasonal migration along the eastern coast of North America (with a peak during summer). They have been observed feeding along the northern edge of the Bank during summer.

Known Vulnerabilities

Significant threats to this species are activities that injure or cause fatalities. All known-human induced mortality to right whales is due to entanglements in fishing gear or vessel strikes. Potential threats to right whales and to their critical habitat associated with oil and gas exploration and extraction have been identified, however, it is not possible to evaluate these threats at this time. The potential threats include noise, vessel disturbance, contaminants, and environmental or habitat change. Potential effects of noise on right whales include displacement, habituation, behavioural changes, temporary or permanent hearing impairment, acoustic masking, and even mortality.

The potential effects of vessel disturbance have not been evaluated, however, vessel activity may affect the behaviour of right whales (e.g. disturb feeding or nursing) or displace whales from rich food patches. Contaminants may affect the survival or reproductive success of right whales, although no such cases have been documented to date. The potential effects of environmental change are uncertain. Threats to critical habitat would likely have to degrade prey productivity and quality, alter the oceanographic and bathymetric features that lead to prey aggregation, or exclude whales from an area of critical habitat (Brown et al., 2009).

Status Designation

Right whale was listed as 'endangered' in 2005 pursuant to SARA. Right whales were considered a single species and designated 'endangered' by COSEWIC in 1980. Its status was re-examined and determined to be 'endangered' in April 1985 and again in April 1990. In May 2003, the species was split into two (the North Atlantic and North Pacific *Eubalaena japonica* right whales) to allow a separate designation of the North Atlantic right whale. The North Atlantic right whale was designated 'endangered' by COSEWIC in May 2003.

2.9.1.2 Fin Whale

Distribution, Habitat, Abundance, and Predator and Prey

Fin whales, *Balaenoptera physalus*, have a global distribution and are often found in deep, offshore waters of all major oceans; primarily in temperate to polar latitudes and less commonly at ice edges and equatorial areas. Fin whales are associated with low surface temperatures and oceanic fronts during summer months. In the western North Atlantic, they are found from close inshore to well beyond the shelf break. They generally make seasonal migrations from tropical wintering areas to temperate summer feeding grounds and, as a result, the density of individuals in an area changes seasonally.

The fin whale is a filter-feeder, feeding on small schooling fish such as herring and capelin, squid, and crustaceans, including mysids and krill, though this varies geographically and seasonally. The current abundance and level of depletion compared with pre-whaling numbers are uncertain. Pre-commercial whaling estimates for the North Atlantic population are in the order of 30,000-50,000 individuals. The best available recent estimates for parts of the western North Atlantic, however, are 2269 individuals (Coefficient of Variance, CV=0.37) between Georges Bank and the mouth of the Gulf of St. Lawrence in 2006 (Waring et al., 2009). It remains unknown whether this population is stable, increasing, or decreasing.

Population Structure Relative to Moratorium Area

Fin whales are present on Georges Bank throughout the year, as the species undergo seasonal migrations in the western north Atlantic. Fin whales have been sighted in Canadian waters year-round on Georges Bank. They are found from inshore areas to the offshore, beyond the edge of the continental shelf. Fin whales are associated with oceanic fronts known for high biological productivity and low water temperatures in summer months, when they concentrate in the Gulf of St. Lawrence, on the Scotian Shelf, in the Bay of Fundy, off Newfoundland, and off Labrador.

Life History, Location, and Timing

Fin whales reach physical maturity and sexual maturity at 5-15 years for both sexes, with the average reported as 6-7 years for males and 7-8 years for females. Little information is available on where they spend their winter months or the location of calving and breeding areas. Mating is believed to occur in temperate, low-latitude areas during the winter, followed by an 11-12 month gestation period. A calf weans from its mother at 6 or 7 months of age and then follows the mother to the winter feeding ground (COSEWIC, 2005b). Females reproduce every 2-3 years, with as many as 6 fetuses being reported, although single births are far more common.

Known Vulnerabilities

The whales face a number of current threats, but none are believed to seriously threaten the population (COSEWIC, 2005b). Threats to the population include entanglements in fishing gear, vessel strikes, noise, vessel disturbance, contaminants, and environmental or habitat change. Potential effects of noise on fin whales include habituation, behavioural changes, temporary or permanent hearing impairment, acoustic masking, and even mortality. Vessel activity may affect the whales behaviour (e.g. disturb feeding or nursing) or displace whales from rich food patches (COSEWIC, 2005b).

Status Designation

Fin whale is listed as a species of 'special concern' pursuant to SARA. Fin whales were considered a single species and designated as 'special concern' by COSEWIC in April 1987. In May 2005, the species was split into two populations (Atlantic and Pacific) and the Atlantic population was designated as 'special concern' by COSEWIC.

2.9.1.3 Sei Whale

Distribution, Habitat, Abundance, and Predator and Prey

Sei whales, *Balaenoptera borealis*, are distributed throughout all of the world's oceans. In Atlantic Canadian waters, sei whales range from Georges Bank in the south to Labrador in the north. During the summer and early autumn months, a major portion of the northwest Atlantic sei whale population may be found on the Scotian Shelf (Mitchell and Chapman, 1977). The southern portion of their range during spring and summer includes the Gulf of Maine and Georges Bank, with sightings concentrated along the eastern margin of Georges Bank and along the southwestern edge of Georges (Waring et al., 2007).

Sei whales use primarily pelagic habitats and are most often found in deeper waters, up to the 2000 m depth contour. They appear to be associated with the continental shelf edge in the northwest Atlantic (Waring et al., 2009). Little is known about the location of breeding. This baleen whale feeds mainly on copepods and other zooplankton floating in the upper layers in the water column. Current population abudance in the northwest Atlantic is unknown. Waring et al. (2009) provided an estimate of 386 individuals (CV=0.85) for the Nova Scotia stock, based on an August 2004 line-transect sighting survey.

Population Structure Relative to Moratorium Area

Mitchell and Chapman (1977) suggested that the sei whales in this area could be separated into a Nova Scotia stock and a Labrador Sea stock. The range of the Nova Scotia stock includes the continental shelf waters of the northeastern U.S. and extends northeastward to south of Newfoundland. There is less evidence to support existence of a Labrador stock. Sei whales are present on Georges Bank throughout the year, although they are concentrated in the area during the spring and early summer.

Life History, Location, and Timing

Sei whales reach sexual maturity between 5-15 years of age and have an estimated lifespan of 50-70 years. Females breed every 2-3 years and have a gestation period of 10- 12 months. Conception and calving occurs in winter in lower latitudes. Calves are weaned on the feeding grounds after a lactation period of approximately 6 months.

Known Vulnerabilities

Threats to the sei whale population include entanglements in fishing gear, vessel strikes, noise, vessel disturbance, contaminants, and environmental or habitat change. Potential effects of noise on sei whales include habituation, behavioural changes, temporary or permanent hearing impairment, acoustic masking, and even mortality. Vessel activity might affect the behaviour (e.g. disturb feeding or nursing) or displace whales from rich food patches.

Status Designation

Sei whales in the northwest Atlantic are not listed pursuant to SARA (the Pacific population is listed as 'endangered'). In May 2003, COSEWIC designated the Atlantic population as 'data deficient'.

2.9.1.4 Minke Whale

Distribution, Habitat, Abundance, and Predator and Prey

Minke whales, *Balaenoptera acutorostrata*, are found in all of the world's oceans. Whales sighted along the eastern coast of Canada and the U.S. are considered to be members of the Canadian East Coast stock, which inhabits the area from the eastern half of the Davis Strait in the north to the Gulf of Mexico. The relationship between the Canadian East Coast stock and the other three stocks in the Atlantic is uncertain (i.e. West Greenland, central North Atlantic, and northeast North Atlantic). It is also uncertain if there are separate subpopulations in the Canadian East Coast stock. During the spring and summer minke whales can be found throughout their range in the northwest Atlantic. Sightings are less common in Canadian waters during the late autumn and winter (Waring et al., 2009).

Minke whales generally occur along the continental shelf. Minke whales opportunistically feed on crustaceans (e.g. krill), plankton (e.g. copepods), and small schooling fish such as dogfish, capelin, cod, eels, herring, mackerel, salmon, sand lance, and wolfish (Waring et al., 2007). The current population abundance of minke whales is unknown. Waring et al. (2009) provided a best population estimate of 3312 whales in 2006 (CV=0.74), for an area ranging from Georges Bank to the mouth of the Gulf of St. Lawrence.

Population Structure Relative to Moratorium Area

Minke whales are usually present on Georges Bank during the spring, although some can be observed during the summer.

Life History, Location, and Timing

The estimated lifespan of minke whales is 50 years. Minke whales reach maturity at approximately 6 years of age for males and 7 years of age for females. Breeding is thought to occur during the winter and calving occurs during early winter. After a gestation period of 10-11 months, females give birth to a single calf. Calving locations and over-wintering habitat has not been described, although they are likely located in tropical or sub-tropical waters (Waring et al., 2007).

Known Vulnerabilities

Minke whales face the same threats as other large whales, although none are believed to seriously threaten the population (Waring et al., 2009). Threats to the population include entanglements in fishing gear, vessel strikes, noise, vessel disturbance, contaminants, and environmental or habitat change. Potential effects of noise on minke whales include habituation, behavioural changes, temporary or permanent hearing impairment, acoustic masking, and even mortality. Vessel activity might affect the behaviour (e.g. disturb feeding or nursing) or displace whales from rich food patches.

Status Designation

Minke whale in the northwest Atlantic are not listed pursuant to SARA. In April 2006, COSEWIC designated both the Atlantic and Pacific populations as 'not at risk'.

2.9.1.5 Humpback Whale

Distribution, Habitat, Abundance, and Predator and Prey

Humpback whales, *Megaptera novaeangliae*, are distributed throughout the world's oceans. In the western Atlantic, they are found from the West Indies to Greenland. In eastern Canada, humpback whales are common in the summer and are typically sighted from the Gulf of Maine to southeastern Labrador. Humpback whales form relatively discrete subpopulations that exhibit distinct seasonal patterns. Humpback whales in the Gulf of Maine constitute a separate feeding stock due to the strong fidelity to the region (Waring et al., 2009). Most sightings occur in relatively coastal waters. In general, during the autumn, humpbacks migrate southward to winter and breed in tropical waters. During the spring they return to northern feeding grounds for the summer.

Humpback whales are seasonal feeders and carnivores that filter feed tiny crustaceans (e.g. krill, mainly *Euphausia superba*, copepods, etc.), plankton, and small fish (including herring, mackerel, capelin, and sandeel) from the water. The Gulf of Maine humpback whale stock appears to be increasing in abundance and a best population estimate for the subpopulation is 847 whales (CV=0.41) (Waring et al., 2009). Population estimates for the remainder of eastern Canadian waters are problematic due to uneven sampling.

Population Structure Relative to Moratorium Area

Humpback whales undergo extensive seasonal migrations and, as such, can be found on Georges Bank for much of the year, although they are absent, for the most part, during the winter (Waring et al., 2009). Humpback whales have a number of quite distinct feeding aggregations. One aggregation occurs in the Georges Bank and Gulf of Maine region, with a population size of several hundred individuals.

Life History, Location, and Timing

Humpback whales reach sexual maturity at about 9 years of age. A female gives birth to one calf between January and April. The gestation period is approximately one year. Normally, females give birth every two years.

Known Vulnerabilities

Humpback whales face the same threats as other large whales but none are believed to seriously threaten the population. Threats to the population include entanglements in fishing gear, vessel strikes, noise, vessel disturbance, contaminants, and environmental or habitat change. Potential effects of noise on humpback whales include habituation, behavioural changes, temporary or permanent hearing impairment, acoustic masking, and even mortality. Vessel activity might affect the behaviour (e.g. disturb feeding or nursing) or displace whales from rich food patches.

Status Designation

Humpback whale in the northwest Atlantic is listed as 'special concern' pursuant to SARA (Pacific humpbacks are listed as threatened). In May 2003, COSEWIC designated the Atlantic population as 'not at risk'.

2.9.1.6 Sperm Whale

Distribution, Habitat, Abundance, and Predator and Prey

Sperm whales, *Physeter macrocephalus*, are found throughout the world's oceans in deep waters, over 1000 m deep, between about 60° N and 60° S latitudes. They may also be seen closer to shore in areas where the continental shelf is small and water depths increase to 310-920 m (Shirihai and Jarrett, 2006). Their distribution is dependent on their food source and suitable conditions for breeding, which varies with the sex and age composition of the group. Sperm whales off eastern Canada and U.S. are thought to belong to a single north Atlantic population.

Female sperm whales are typically found in deep waters of low latitudes where sea surface temperatures are greater than 15 °C. Immature males will stay with female sperm whales in tropical and subtropical waters until they begin to slowly migrate towards the poles, anywhere between ages 4-21 years of age. Older, larger males are generally found near the edge of pack ice in both hemispheres. On occasion, however, these males will return to the warm water breeding area (Waring et al., 2007).

This toothed whale is generally a deep-water species with a diet mainly consisting of mesopelagic and benthic squids, but fishes also form part of their diet. Available data are insufficient to determine the population trend for this species. Waring et al. (2007) indicated that the best estimate of abundance for sperm whales in the northwest Atlantic is 4804 whales (CV=0.38).

Population Structure Relative to Moratorium Area

Typically males are found on Georges Bank year round near the continental slope, as females and young are usually found at latitudes less than about 40 ^{0}N. In winter, sperm whales are concentrated east and northeast of Cape Hatteras. In spring, the centre of distribution shifts northward to east of Delaware and Virginia, with it being widespread throughout the central portion of the Mid-Atlantic Bight and the southern portion of Georges Bank. In summer, the distribution is similar but also includes the areas east and north of Georges Bank and into the Northeast Channel region, as well as the continental shelf south of New England. In the fall, sperm whale occurrence south of New England on the continental shelf is at its highest levels and there remains a continental shelf edge occurrence in the Mid-Atlantic Bight (Waring et al., 2007).

Life History, Location, and Timing

In the northwest Atlantic, the gestation period for sperm whales is about 14-17 months, births occur mainly in July to November, and the calving interval is 4-6 years. The mean age at sexual maturity is 19 years for males and nine years for females.

Known Vulnerabilities

Sperm whales face the same threats as other large whales but none are believed to seriously threaten the population. Threats to their population include entanglements in fishing gear, vessel strikes, noise, vessel disturbance, contaminants, and environmental or habitat change. Potential effects of noise on sperm whales include habituation, behavioural changes, temporary or permanent hearing impairment, acoustic masking, and even mortality. Because of their deep-diving behaviour, sperm whales may be more susceptible to noise (Houser et al., 2001). Vessel activity might affect the behaviour (e.g. disturb feeding or nursing) or displace whales from rich food patches.

Status Designation

Sperm whales in the northwest Atlantic are not listed pursuant to SARA. In April 1996, COSEWIC designated both the Atlantic and Pacific populations as 'not at risk'.

2.9.1.7 Pilot Whale

Distribution, Habitat, Abundance, and Predator and Prey

There are two species of pilot whales in the western Atlantic: the Atlantic or long-finned pilot whale, *Globicephala melas*, and the short-finned pilot whale, *G. macrorhynchus*. In late spring, pilot whales generally move from U.S. waters onto Georges Bank and into more northerly Canadian waters. They remain in these areas through late autumn. Longfin pilot whales are more common in Canadian waters. Pilot whales feed primarily on squid. Waring et al. (2007) provided a best estimate of abundance for *Globicephala* sp. of 31,139 animals (CV=0.27), derived from surveys undertaken in 2004.

Population Structure Relative to Moratorium Area

Pilot whales can be found on Georges Bank throughout the year, although they are most prevalent during the spring and summer.

Life History, Location, and Timing

For pilot whales in Canadian waters, the gestation period is approximately 1 year, births occur mainly from June to November, and the calving interval is around three years. The mean age at sexual maturity is 12 years for males and 6 years for females.

Known Vulnerabilities

Threats to pilot whales include entanglements in fishing gear, vessel strikes, noise, vessel disturbance, contaminants, and environmental or habitat change. Potential effects of noise on pilot whales include habituation, behavioural changes, temporary or permanent hearing impairment, acoustic masking, and even mortality. Vessel activity might affect the behaviour (e.g. disturb feeding or nursing) or displace whales from rich food patches.

Status Designation

Pilot whales in the northwest Atlantic are not listed pursuant to SARA. In April 1994, COSEWIC designated the Atlantic population as 'not at risk'.

2.9.1.8 Bottlenose Dolphin

Distribution, Habitat, Abundance, and Predator and Prey

Bottlenose dolphins, *Tursiops truncates*, are distributed from the tropics to southern Canadian waters. The bottlenose dolphin is rare in Canadian waters, where it is at the northern limits of its range. Two forms of the species are recognized: coastal and offshore. The offshore species is distributed primarily along the outer continental shelf and continental slope in the northwest Atlantic.

Bottlenose dolphins are generalists and feed on a variety of prey items endemic to their habitat. The species has a broad diet consisting of fish, squids and invertebrates. Coastal animals prey on benthic invertebrates and fish. Offshore animals feed on pelagic squid and fish. There are no estimates of bottlenose dolphins for Canadian waters, although NOAA Fisheries has estimated abundance in the northern migratory component of the Atlantic coastal form to be 17,466 animals (Waring et al., 2007). This popuation unit may extend into Canadian waters.

Population Structure Relative to Moratorium Area

Bottlenose dolphins are found on Georges Bank throughout the year and have a higher prevalence in spring and summer (Waring et al., 2007).

Life History, Location, and Timing

Calving of bottlenose dolphins is suggested to occur primarily from early spring to early autumn, estimates of gestation period range from 11-14 months, calves are weaned at an average age of 18-20 months, and the intercalf interval is estimated to be from 1.3-2 years. Age at sexual maturity averages 11 years for males (ranging from 9-20 years) and 12 years for females (ranging from 3.5-14 years).

Known Vulnerabilities

Threats to bottlenose dolphins include entanglements in fishing gear, noise, vessel disturbance, contaminants, and environmental or habitat change. Potential effects of noise on bottlenose dolphins include habituation, behavioural changes, temporary or permanent hearing impairment, acoustic masking, and even mortality. Vessel activity might affect the behaviour (e.g. disturb feeding or nursing) or displace dolphins from rich food patches.

Status Designation

Bottlenose dolphins in the northwest Atlantic are not listed pursuant to SARA. In April 1993, COSEWIC designated both the Atlantic and Pacific populations as 'not at risk'.

2.9.1.9 Atlantic White-sided Dolphin

Distribution, Habitat, Abundance, and Predator and Prey

White-sided dolphins, *Lagenorhynchus acutus*, are distributed throughout the continental shelf and slope areas of temperate and sub-polar waters of the North Atlantic. The species inhabits waters from central West Greenland to North Carolina. This species exhibits seasonal movements, moving closer inshore and north in the summer and offshore and south in the winter.

The Atlantic white-sided dolphin feed primarily on fish (such as sand lance, herring, and silver hake) and squid. No estimate of the population trend for white-sided dolphins exists. The best available current abundance estimates for white-sided dolphins in the western North Atlatnic is 63,368 (CV=0.27) for the area from Georges Bank to the mouth of Gulf of St. Lawrence (Waring et al., 2009).

Population Structure Relative to Moratorium Area

Available data concerning distribution suggest the possible existence of three stocks units: Gulf of Maine, Gulf of St. Lawrence, and Labrador Sea stocks (Palka et al., 1997). White-sided dolphins are highly prevalent on and around Georges Bank for most of the year, with a decline over the winter as the species moves further south.

Life History, Location, and Timing

White-sided dolphins have a lifespan of approximately 25 years. The mean age at sexual maturity is 8-9 years for males and 6-8 years for females. For white-sided dolphins in Canadian waters, the gestation period is about 10-12 months, births occur from May to early August, mainly in June and July, and the calving interval is 2-3 years.

Known Vulnerabilities

Threats to Atlantic white-sided dolphins include entanglements in fishing gear, noise, vessel disturbance, contaminants, and environmental or habitat change. Potential effects of noise on Atlantic white-sided dolphins include habituation, behavioural changes, temporary or permanent hearing impairment, acoustic masking, and even mortality. Vessel activity might affect the behaviour (e.g. disturb feeding or nursing) or displace dolphins from rich food patches.

Status Designation

Atlantic white-sided dolphin in the northwest Atlantic is not listed pursuant to SARA. In April 1991, COSEWIC designated both the Atlantic and Pacific populations as 'not at risk'.

2.9.1.10 Common Dolphin

Distribution, Habitat, Abundance, and Predator and Prey

The common dolphin, *Delphinus delphis,* may be one of the most widely distributed species of cetaceans, as it is found world-wide in temperate, tropical, and subtropical seas. Their distributions vary based on interannual changes, oceanographic conditions, and seasons. They can occur on the continental shelf or further offshore. In the northwest Atlantic, they are more common north of Cape Hatteras, North Carolina. During summer through autumn, large aggregations can be found near Georges Bank, Newfoundland, and the Scotian Shelf.

Common dolphins prefer warm tropical to cool temperate waters (10-28 °C) that are primarily oceanic and offshore, but still along the continental slope in waters 200-2000 m deep. In the western North Atlantic, they are often associated with the Gulf Stream Current. Short-beaked common dolphins also prefer waters altered by underwater geologic features where upwelling occurs. The diet of the common dolphin consists of epipelagic schooling fish and cephalopods (e.g. squid). No estimate of trend in abundance exists for common dolphins. The most recent estimate of abundance is derived from surveys by the NEFSC in 2004. Abundance was estimated as 90,547 for the area ranging from Maryland to the Bay of Fundy and 120,743 for Florida to the Bay of Fundy (Waring et al., 2007).

Population Structure Relative to Moratorium Area

Common dolphins are highly prevalent on Georges Bank during the winter season. They range from Cape Hatteras to Georges Bank during mid-January to May and move onto Georges Bank and the Scotian Shelf from mid-summer to autumn. Large aggregations have been reported on the bank in autumn. Migration onto the Scotian Shelf and continental shelf off Newfoundland occurs during summer and autumn when water temperatures exceed 11 ºC (Waring et al., 2007).

Life History, Location, and Timing

Male common dolphins become sexually mature between 3-12 years and females between 2-7 years. Breeding usually takes place between the months of June and September, followed by a 10-11 month gestation period. Females give birth to a single calf and have an estimated calving interval of 1-3 years. Calving can occur annually and lactation lasts approximately 4 months. They have an estimated lifespan of up to 35 years.

Known Vulnerabilities

Threats to common dolphins include entanglements in fishing gear, noise, vessel disturbance, contaminants, and environmental or habitat change. Potential effects of noise on common dolphins include habituation, behavioural changes, temporary or permanent hearing impairment, acoustic masking, and even mortality. Vessel activity might affect the behaviour (e.g. disturb feeding or nursing) or displace dolphins from rich food patches.

Status Designation

Common dolphins in the northwest Atlantic are not listed pursuant to SARA. In April 1991, COSEWIC designated both the Atlantic and Pacific populations as 'not at risk'.

2.9.1.11 Striped Dolphin

Distribution, Habitat, Abundance, and Predator and Prey

The striped dolphin, *Stenella coeruleoalba*, is distributed worldwide in warm-temperate to tropical waters that are oceanic and deep. In the western North Atlantic, striped dolphins are distributed along the continental shelf edge from Cape Hatteras to the southern margin of Georges Bank and also occur offshore over the continental slope and rise in the Mid-Atlantic region. In general, striped dolphins appear to prefer continental slope waters offshore to the Gulf Stream. These dolphins are often linked to upwelling areas and convergence zones.

Striped dolphins feed on a diverse diet consisting of various species of relatively small, closely-packed, midwater, 'benthopelagic' and/or 'pelagic' shoaling/schooling fish (e.g. 'myctophids' and cod) and cephalopods (e.g. squid and octopus) throughout the water column. No estimate of trend in abundance exists for striped dolphins. The most recent estimate of abundance is derived from surveys by NEFSC in 2004. Abundance was estimated as 50,055 (CV=0.57) for the area ranging from Maryland to the Bay of Fundy, and 94,462 (CV=0.40) for Florida to the Bay of Fundy (Waring et al., 2007).

Population Structure Relative to Moratorium Area

Little information exists concerning population structure in the western North Atlantic. The striped dolphin is mostly found on Georges Bank during the summer and fall.

Life History, Location, and Timing

Striped dolphins become sexually mature between the ages of 5-13 years for females and 7-15 years for males. Their mating system is generally unknown but thought to be polygynous. They give birth to a single calf during the summer or autumn after a gestation period of about one year. The interval between giving birth to calves is usually 3-4 years and lactation lasts 12-18 months. The estimated lifespan of these dolphins is up to 58 years.

Known Vulnerabilities

Threats to striped dolphins include entanglements in fishing gear, noise, vessel disturbance, contaminants, and environmental or habitat change. Potential effects of noise on striped dolphins include habituation, behavioural changes, temporary or permanent hearing impairment, acoustic masking, and even mortality. Vessel activity might affect the behaviour (e.g. disturb feeding or nursing) or displace dolphins from rich food patches.

Status Designation

Striped dolphins in the northwest Atlantic are not listed pursuant to SARA. In April 1993, COSEWIC designated both the Atlantic and Pacific populations as 'not at risk'.

2.9.1.12 Harbour Porpoise

Distribution, Habitat, Abundance, and Predator and Prey

Northwest Atlantic harbour porpoises, *Phocoena phocoena*, are widely distributed over the continental shelves of the northern hemisphere, generally within 250 kilometres of shore. The species is well adapted to cold water and is seldom found in water warmer than 16°C. They are often sighted very close to shore in harbours and bays, particularly in the summer. In Canada, harbour porpoise range from the Bay of Fundy to northern Labrador, with three distinct populations in Newfoundland and Labrador, the Gulf of St. Lawrence, and the Bay of Fundy/Gulf of Maine. These populations regularly travel down to American waters and back to Canada (COSEWIC, 2006d). Harbour porpoise feeds mainly on small fishes such as herring, but a variety of other fishes (cod, capelin and sand lance) are also found in its diet.

There are no range-wide estimates of the abundance of harbour porpoises in eastern Canada and, in fact, much of the range of the species has never been surveyed. Surveys have been conducted in the Gulf of St. Lawrence and the Bay of Fundy-Gulf of Maine and in 2007 in Newfoundland or Labrador. Surveys in the Gulf of St. Lawrence during the summers of 1995 and 1996 provided estimates of 12,100 and 21,720 porpoises, respectively, while the most recent estimate (August 1999) of subpopulation size in the Bay of Fundy and Gulf of Maine was 89,700 (COSEWIC, 2006d). An uncorrected estimate of 1195 porpoises was derived following a survey that included waters of Newfoundland and Labrador (Lawson and Gosselin, 2009), but this estimate is lower than the approximately 7000 (uncorrected) estimated from a previous smaller-scale survey conducted around Newfoundland in 2002-2003 (pers comm. J. Lawson, DFO).

Population Structure Relative to Moratorium Area

The harbour porpoise undergoes a spring migration through the Georges Bank area to reach coastal summer feeding grounds. The population of porpoises in the Bay of Fundy and Gulf of Maine is transboundary in nature, moving frequently between Canadian and U.S. waters.

Life History, Location, and Timing

Reproduction in all harbour porpoise populations is seasonal, with ovulation and conception limited to a few weeks in early summer. Gestation lasts for 10-11 months followed by a lactation period of at least 8 months. Most mature female porpoises become pregnant each year. In the Bay of Fundy, mean age at sexual maturation for male and female porpoises was estimated to be 2.6 and 3.44 years, respectively. The harbour porpoise lifespan is approximately 24 years (COSEWIC, 2006d).

Known Vulnerabilities

The most significant threat to harbour porpoise may be entanglement in fishing gear, especially groundfish gillnets. Other threats that have been identified include habitat degradation, loss of habitat due to acoustic harassment devices used by commercial fish-farmers, and environmental contaminants.

Status Designation

At the time SARA was passed, Harbour Porpoise was listed as 'threatened' under Schedule II of SARA. It is currently being considered for listing as 'special concern' on Schedule I of SARA. Harbour porpoise was designated as 'threatened' by COSEWIC in April 1990. Its status was re-examined and confirmed in April 1991. It was then downlisted to 'special concern' in May 2003.

2.9.1.13 Blue Whale

Distribution, Habitat, Abundance, and Predator and Prey

Blue whales, *Balaenoptera musculus,* are found in all the oceans of the world and inhabit both coastal waters and the open ocean. Individuals belonging to the Atlantic population are observed in the St. Lawrence estuary and shallow coastal zones where the mixing of waters ensures high productivity of krill (the main food source). Three subspecies are recognized, with the Northern Hemisphere subspecies frequenting Canadian waters. Two geographically separated populations exist in Canadian waters: one in the North Atlantic and the other in the North Pacific

Blue whales are known to feed almost exclusively on euphausiids worldwide. In the North Atlantic, *Thysanoessa inermis*, *Thysanoessa raschii*, *T. longicaudata*, and *Meganyctiphanes norvegica* have been recognized as the principal blue whale prey. Blue whales feed along productive cold water upwellings in temperate to polar waters from spring to early winter. They have been described as fasting after leaving the feeding grounds (COSEWIC, 2002). Blue whale feeding aggregations are often found at the continental shelf edge where upwelling produces concentrations of krill.

Global blue whale population estimates are thought to range from 5000-12,000 individuals, although a reliable recent global population estimate does not exist. Likewise, there are no population estimates for the Atlantic population, although it is unlikely that the number of mature animals exceeds 250 individuals (Beauchamp et al., 2009). From 20-105 blue whales are seen annually in the Gulf of St. Lawrence in photo identification studies. From 1979 to the spring of 2007, a total of 405 blue whales have been photo-identified in the estuary and northwest of the Gulf of St. Lawrence (Beauchamp et al., 2009).

Population Structure Relative to Moratorium Area

During spring, summer, and fall the Atlantic population of blue whales occurs along the north shore of the Gulf of St. Lawrence and off eastern Nova Scotia. In summer, they also occur off the coast of Newfoundland and in the Davis Strait. While they usually migrate south for the winter, some whales may remain in the Gulf of St. Lawrence. Although they are rare in the shelf waters off the eastern U.S., there have been occasional sightings off Cape Cod. It is believed this region may represent the current southern limit of the blue whales' feeding range. Sightings on Georges Bank are not common.

Life History, Location, and Timing

Blue whales mate and calve from late fall to mid-winter in the Northern Hemisphere and give birth to a single calf every 2-3 years after a 10-11 month gestation period. The age of sexual maturity is believed to be 5-15 years (Waring et al., 2007).

Known Vulnerabilities

Historical commercial whaling of blue whales is the main factor responsible for the decline in the North Atlantic population. At least 11,000 blue whales were harvested in the North Atlantic before 1960. Approximately 1500 of these were harvested in eastern Canadian waters from 1898-1951. Today, the biggest threats for this species come from ship strikes, disturbance from seismic exploration, increasing whale watching activity, entanglement in fishing gear, and pollution. Vessel activity might affect the behaviour (e.g. disturb feeding or nursing) or displace whales from rich food patches. They also may be vulnerable to long-term changes in climate, which could affect the abundance of their prey (zooplankton) (Beauchamp et al., 2009).

Status Designation

Blue whale was listed as 'endangered' pursuant to SARA in 2005. In April 1983, COSEWIC designated the entire Canadian population of blue whales as 'special concern'. In May 2002, blue whales were split into two populations and the Atlantic population was up-listed to 'endangered' by COSEWIC in May 2002.

2.9.1.14 Sowerby's Beaked Whale

Distribution, Habitat, Abundance, and Predator and Prey

Sowerby's beaked whales, *Mesoplodon bidens,* are found only in the North Atlantic. Their distribution is poorly known, as few at-sea sightings have been confirmed. From these limited data and shore stranding locations, they are considered to be the most northern North Atlantic species of the genus *Mesoplodon* (beaked whales), ranging offshore from Cape Cod to Davis Strait in the western Atlantic and from Norway to Spain in the eastern Atlantic. In the mid-Atlantic the species ranges from Iceland to the Azores and Madeira.

This species is most often sighted in deep water, along the continental shelf edge and slope and is rare in coastal waters. Sightings of this species in Canadian waters are considered rare (COSEWIC, 2006e). Sowerby's beaked whales are considered deep divers with a diet consisting mainly of deep-sea fishes and squid. No estimate of population size or number of mature individuals within Canadian waters exists for Sowerby's beaked whales (COSEWIC, 2006e).

Population Structure Relative to Moratorium Area

There are no known seasonal movements or migrations of this species.

Life History, Location, and Timing

Little is known about the biology of Sowerby's beaked whales. Their breeding season may be from late winter to spring. They age of sexual maturity is thought to be 7 years, although the estimated lifespan of this species remains unknown (Waring et al., 2007).

Known Vulnerabilities

Potential threats include noise, vessel disturbance, ship strikes, fishing gear entanglement, and contaminants. Some potential effects of noise on Sowerby's beaked whales include habituation, behavioural changes, temporary or permanent hearing impairment, acoustic masking, and even mortality. Incidents involving beaked whale strandings near naval exercises that used mid-frequency sonar suggest a need for caution in conducting seismic surveys in areas occupied by beaked whales. Changes in behaviour and in distribution have been observed in some whale species after seismic surveys. Sowerby's beaked whales also may be vulnerable to other sources of acoustic pollution. Vessel activity might affect the behaviour (e.g. disturb feeding or nursing) or displace whales from rich food patches. Contaminants may affect the survival or reproductive success, although no such cases have been documented to date (COSEWIC, 2006e).

Status Designation

Sowerby's beaked whale is currently listed as special concern pursuant to SARA. In November 2006, COSEWIC designated Sowerby's beaked whale as a 'species of special concern'.

2.9.2 Seals

Two species of seals (i.e. grey seals and harbour seals) are known to frequent the Georges Bank moratorium area. These are described in more detail below. Two other seal species (i.e. hooded and harp seals) are considered to be infrequent visitors of the area and are not described.

2.9.2.1 Grey Seals

Distribution, Habitat, Abundance, and Predator and Prey

Grey seals, *Halichoerus grypus*, are found on both sides of the North Atlantic, with three major populations: Baltic Sea, northwestern Europe and eastern Canada. The North western Atlantic population, which ranges from the Gulf of Maine to southern Labrador (Figure 2-97), forms a single genetic population, but are divided into three components for management purposes based on the location of main breeding concentrations (Sable Island, Gulf of St. Lawrence and Eastern Shore). The western North Atlantic stock has a cold temperate to sub-Arctic distribution over the continental shelf and coastal waters, preferring areas with water depths less than 200 m. On land, they inhabit rocky coasts and islands, sandbars, and ice shelves and icebergs (Waring et al., 2007; DFO, 2008e).

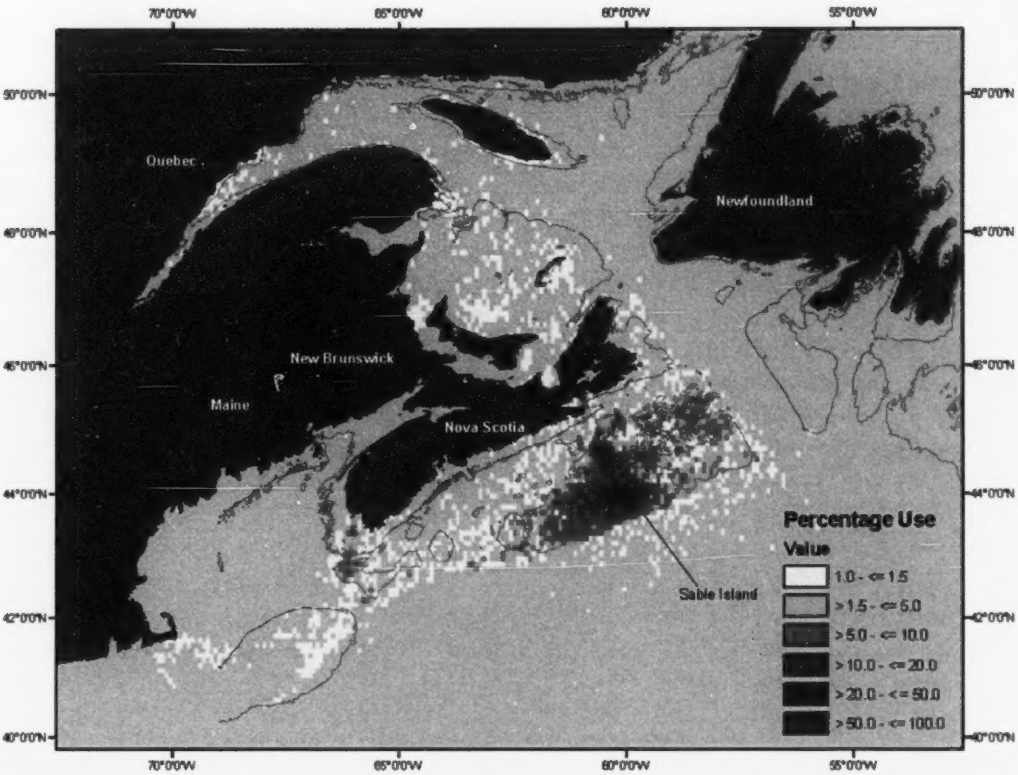

70°0'0"W
65°0'0"W
60°0'0"W
55°0'0"W
50°0'0"N
48°0'0"N
46°0'0"N
44°0'0"N
42°0'0"N
40°0'0"N
Quebec
Newfoundland
New Brunswick
Maine
Nova Scotia
Sable Island
Percentage Use
Value
1.0 - <= 1.5
> 1.5 - <= 5.0
> 5.0 - <= 10.0
> 10.0 - <= 20.0
> 20.0 - <= 50.0
> 50.0 - <= 100.0

Figure 2-97. Annual distribution of adult grey seals, based on locations of 70 animals fitted with Argos satellite tags on Sable Island, demonstrates limited use by the species in the Great Southern Channel, Georges Bank, and the Northeast Channel areas of the Gulf of Maine (Zwanenburg et al., 2006).

Grey seals are generalist predators that consume mainly fish and cephalopods, but crustaceans and sea birds are occasionally taken. Prey species include cod, herring, capelin, sand lance, redfish, haddock, pollock, mackerel, flounder, skates, squid, and crab (Bowen et al., 1993). The total estimated size of the western Atlantic grey seal population at the end of the 2007 breeding season was 304,000. This is 6% higher than the equivalent estimate for 2006 and 750% higher than the estimate for 1977. Average annual rates of population increase are estimated to be 4% in the 1980s, 9% in the 1990s, and 8% in the 2000s (Thomas et al., 2007).

The greatest increase is associated with the Sable Island colony, the largest worldwide, near the edge of the continental shelf in the central Scotian Shelf. Population numbers of the Sable Island colony increased exponentially at an annual rate of 13% per year until the late 1990s, however, recent survey results indicate a slowing in the rate of increase to about 7% per year through 2007 (Figure 2-98) and an increase in the age at first birth (DFO, 2008e).

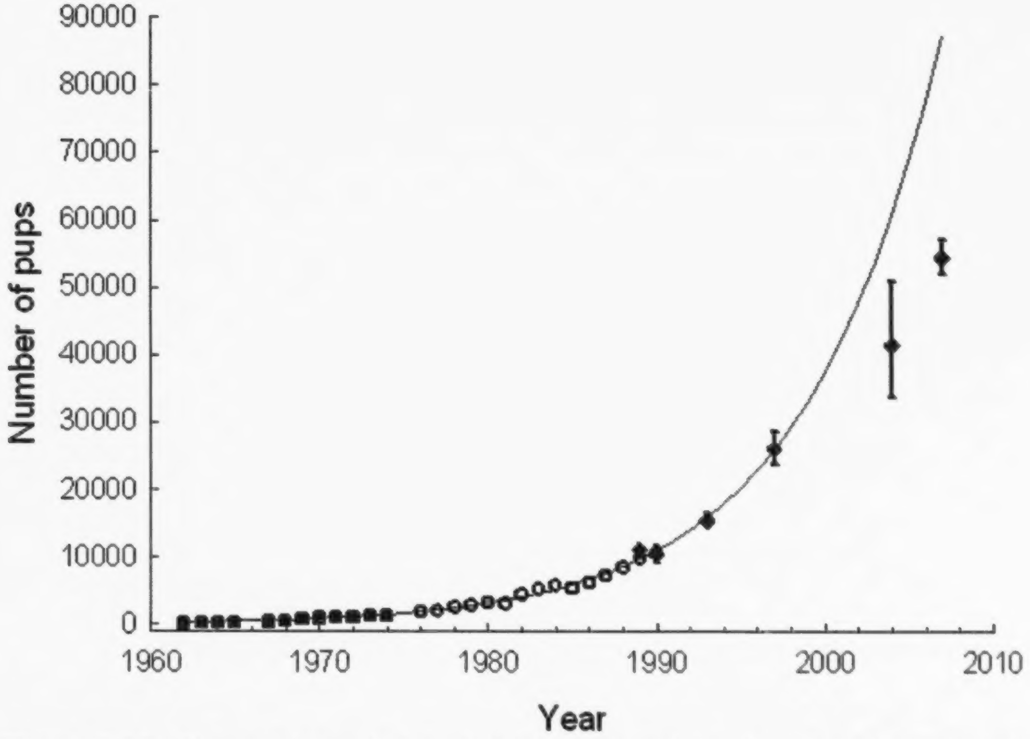


Figure 2-98. Observed trends (symbols) in the number of pups and exponential model estimates (solid line) of the number of grey seal pups born at the Sable Island colony from 1962-2007 (source: Bowen et al., 2007).

Population Structure Relative to Moratorium Area

Although wide-ranging, grey seals are non-migratory, but do show seasonal changes in distribution which are attributed to seasonal changes in prey distribution (Zwanenburg et al., 2006). Adult grey seals from Sable Island travel widely throughout eastern Canadian waters and use the area as foraging habitat (Breed et al., 2009). In addition, a small, year round breeding population is known to occur on outer Cape Cod and Nantucket Island (Waring et al., 2007).

Life History, Location, and Timing

The lifespan for male and female grey seals are 30 and 40 years, respectively. Female grey seals become sexually mature at 4-8 years and males at 4-6 years, although males may not mate successfully until greater than 8 years of age. Mating may occur on islands, isolated beaches, or on the pack ice. The breeding season varies among populations, generally taking place between January and early February. Gestations last for 9 months and pups are born at haul out sites the following year. Pups are weaned at 18 days and moult their birth coat about 4 weeks after birth. Toward the end of the nursing peroid, the adult females mates with one or more males (DFO, 2008e).

Known Vulnerabilities

Grey seals experience incidental capture in fishing gear including gillnets, trawls, seines and weirs. They are also susceptible to boat strikes, oil spill exposure, chemical contaminants and marine debris ingestion (Waring et al., 2007).

Status Designation

Grey seal is not listed pursuant to SARA. In 1999, the grey seal was designated 'not at risk' by COSEWIC.

2.9.2.2 Harbour Seals

Distribution, Habitat, Abundance, and Predator and Prey

Harbour seals, *Phoca vitulina*, are considered the most widely distributed pinniped. They are found in temperate, subarctic, and arctic coastal areas on both sides of the North Atlantic and North Pacific oceans. In the northwest Atlantic, they are distributed from the eastern Canadian Arctic and Greenland to southern New England and New York, and occasionally to the Carolinas. Although the stock structure of the northwestern population is unknown, harbour seals along the eastern Canadian and U.S. coasts are considered a single population (Waring et al., 2007).

Harbour seals inhabit coastal waters of the continental shelf and slope and are also commonly found in bays, rivers, estuaries, and intertidal zones. On land they inhabit rocks, sand and shingle beaches, sand bars, and mud flats (Waring et al., 2007). They are generalist feeders that consume a wide variety of fish, cephalopods, and crustaceans from surface, mid-water, and benthic habitats. Prey species include herring, mackerel, cod, whiting, and flatfish, and occasionally shrimp, crabs, mollusks, and squid (Hammill and Stenson, 2000).

In New England, the population is increasing and currently estimated to be just under 100,000 individuals. During the early 1990s, 3500 harbour seals were counted in the Bay of Fundy, however, a population estimate has not been made (Waring et al., 2007). The population on Sable Island was the largest in eastern Canada during the late 1980s, although the numbers have declined. Similarly, pup production on Sable Island declined from 600 pups in 1989 to approximately 12 pups or fewer in 2002, as a result of increased shark predation and increased land use by grey seals (Bowen et al., 2003; Waring et al., 2007).

Population Structure Relative to Moratorium Area

Harbour seals are year-round inhabitants of coastal waters of eastern Canada and Maine, and occur seasonally along the southern New England to New Jersey coasts from September to late May. Seasonal movement patterns include a general southward movement from the Bay of Fundy to southern New England in autumn and early winter followed by a northward movement from southern New England to Maine and eastern Canada prior to the pupping season (Waring et al., 2007).

Life History, Location, and Timing

The lifespan for male and female harbour seals are 25 and 35 years, respectively. Female harbour seals are sexually mature at 3-5 years and males at 4-6 years. Breeding and pupping typically occur along the coastline from Maine northwards. Unlike other seal species, mating typically takes place in water followed by a gestation peroid of 9 months. The pupping season occurs from May to early June along the Maine coast and progressively later in eastern Canada (Bowen et al., 2003; Waring et al., 2007). Moult (shedding their hair) follows the pupping and mating season. The timing and onset of moult depends on the age and sex of the animal with yearlings moulting first and adult males last (Thompson and Härkönen, 2008).

Known Vulnerabilities

Harbour seals experience incidental capture in fishing gear including gillnets, trawls, seines and weirs. They are also susceptible to boat strikes, oil spill exposure, chemical contaminants, and marine debris ingestion (Waring et al., 2007).

Status Designation

Harbour seal is not listed pursuant to SARA. In 2007, the harbour seal population was designated 'not at risk' by COSEWIC.

2.10 SEA TURTLES

Two species of sea turtle, leatherback and loggerhead, are known to occur regularly on Georges Bank. They are described in detail below. There are also records of Kemp's Ridley and Green sea turtles from the Scotian Shelf. The Canadian Sea Turtle Network has responded to several stranded Kemp's Ridley turtles, including a cold-stunned juvenile recovered in the Bay of Fundy. Both species occasionally occur on Georges Bank, albeit less frequently than leatherbacks and loggerheads, so they are not described in detail here. Select sea turtle species are summarized in the Appendix.

2.10.1 Leatherback Turtle

Distribution, Habitat, Abundance, and Predator and Prey

Adult and subadult leatherback turtles, *Dermochelys coriacea*, in the northwest Atlantic undergo an annual migration between breeding areas at low latitudes and foraging habitat in temperate waters (James et al., 2005a). Leatherback turtles are found in tropical and temperate waters of the Atlantic, Pacific, and Indian Oceans. Leatherbacks that forage in Canadian waters originate (nest) from beaches in South and Central America, the Caribbean, and continental U.S. (James et al., 2007). The west coast of Africa hosts one of the largest remaining nesting populations of leatherbacks in the Atlantic (Witt et al., 2009); this stock does not utilize high latitude foraging areas.

While mature leatherbacks are regularly encountered in temperate waters, records of juveniles are from tropical waters. Little is known about hatchling and juvenile habitat requirements, however, since they are never seen in temperate waters it is assumed that the leatherbacks gain cold tolerance as they mature. The annual return of leatherbacks to northern latitudes of the western Atlantic in late spring through summer (Figure 2-99) coincides with the seasonal availability of gelatinous zooplankton prey (James et al., 2005a,b; James et al., 2006; James et al., 2007), including the lion's mane jellyfish (*Cyanea capillata*), a preferred forage species. Leatherbacks concentrate in areas where productivity is high, along oceanic frontal systems and along vertical gradients located at oceanic fronts.

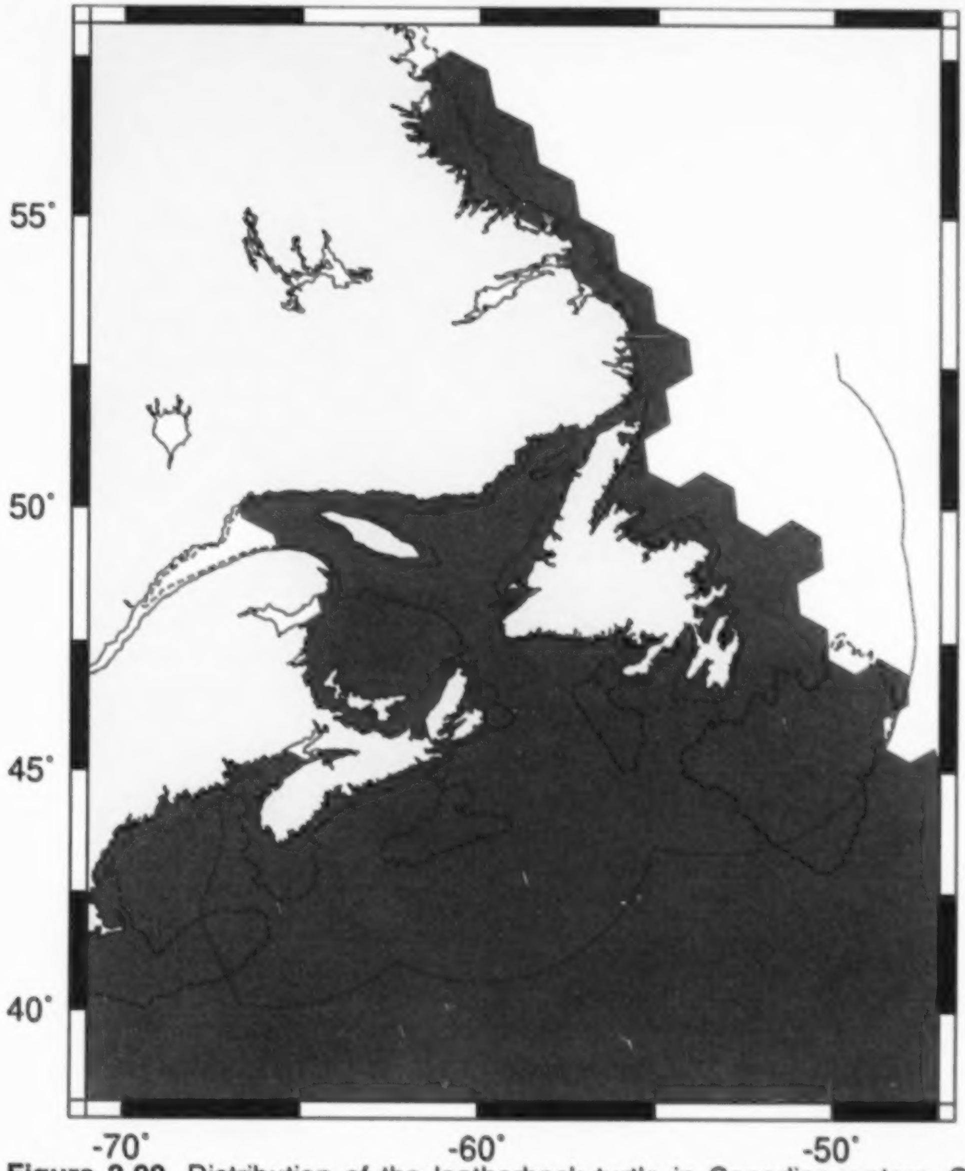


Figure 2-99. Distribution of the leatherback turtle in Canadian waters. Shaded areas represent areas of known occurrence from sightings and satellite telemetry data. Dashed line represents 100m isobath. Solid line denotes Canadian 200 mile limit (Exclusive Economic Zone).

Prey consumed by leatherbacks in temperate northwest Atlantic waters includes several species of gelatinous zooplankton (e.g. *Cyanea capillata*) (James and Herman, 2001). Trend analyses for six nesting area management units (i.e. North Caribbean, Western Caribbean, Southern Caribbean/Guianas, Florida, South Africa, and Brazil) suggests that, with the exception of the Western Caribbean, these stocks may currently be stable or increasing (TAWG, 2007). An ocean basin-wide population estimate for leatherbacks in the Atlantic is not available, as only mature female leatherbacks come ashore (to nest). Therefore, only two life history stages (nesting females and hatchling production) can be estimated directly, yielding a North Atlantic population estimate of 34,000-94,000 mature leatherbacks (TAWG, 2007).

The large range in this population estimate reflects uncertainty in nest numbers and extrapolation of these data to adults. In-water survey methods have been infrequent and largely opportunistic, focusing on only a small fraction of leatherback foraging habitat. Apart from the Cetacean and Turtle Assessment Program (CETAP) surveys from 1978-1982 (Shoop and Kenney, 1992), and annual aerial surveys for right whales conducted by the NMFS, waters adjacent to and including portions of the Georges Bank moratorium area have not been regularly surveyed. As such, in-water abundance trends for the moratorium area are not available.

Population Structure Relative to Moratorium Area

The leatherback 'season' in Canadian waters extends from May through December, with the majority of turtles present from July through to mid-October. High use leatherback foraging areas in Atlantic Canada include waters off Cape Breton Island, parts of the south coast of Newfoundland, and southern Gulf of St. Lawrence (James et al., 2005b; James et al., 2006). The largest seasonal concentrations of leatherbacks in the temperate northwest Atlantic occur on the continental shelf and slope, although the species is also present further offshore. Leatherbacks are widely distributed in Atlantic Canada between April and December (James et al., 2005b; James et al., 2006).

Adult and large subadult leatherbacks (curved carapace length greater than 1 m) utilize the Georges Bank moratorium area for foraging. Satellite telemetry studies have revealed that some leatherbacks migrate north to slope waters adjacent to Georges Bank (in the existing moratorium area) in late spring (e.g. James et al., 2005a), where they may remain for several weeks before moving onto the continental shelf. While leatherback distributions on the Scotian Shelf appear to generally shift from southwest to northeast as the foraging season progresses (James et al., 2006; James et al., 2007), slope waters adjacent Georges Bank and, to a lesser extent, waters within the 100 m isobath of Georges Bank, are also used by turtles from late spring through fall (James et al., 2005a).

Slope waters east and southeast of the Northeast Channel provide high use habitat for leatherbacks throughout the summer and fall foraging periods, with some animals departing this area as late as December (Sherrill-Mix et al., 2008). While the temporal window for initiation of southward migration from shelf foraging areas of the northwest Atlantic is relatively narrow, there is considerable variation in departure date among turtles present in offshore foraging areas, including waters corresponding to the Georges Bank moratorium area (Sherrill-Mix et al., 2008). Individual turtles exhibit fidelity for broad foraging zones in the temperate eastern or western Atlantic, however, their routes to and from these areas can vary between years (James et al., 2005b).

Life History, Location, and Timing

Leatherbacks depart temperate foraging areas for tropical and subtropical feeding and breeding areas in the fall. Little information regarding mating, in term of where or when it occurs, is available. The females primarily nest in the tropics on open beaches with minimal amounts of abrasive material. The female leatherback excavates a nest and lays 50-166 eggs. They lay an average of 6 clutches each season at 8-12 day intervals. The eggs hatch in approximately 60-65 days. The sex ratio of the hatchlings is determined by nest temperature during development (COSEWIC, 2001).

Known Vulnerabilities

A long lifespan, very high rates of egg and hatchling mortality, and a late age of maturity (24.5-29 yrs) (Avens et al., 2009) make the leatherback particularly vulnerable to even small increases in rates of mortality among adults and older juveniles. Entanglement in lines associated with fixed fishing gear constitutes the principal source of human-induced injury and mortality for leatherbacks in Canadian waters (James et al., 2005a). Vessel strikes and ingestion of marine debris, particularly plastics (Mrosovsky et al., 2009), constitute additional threats to leatherbacks in the marine environment. While the leatherback's status and biology preclude direct in-situ or captive measurement of physiological and behavioural response to marine noise, some studies (O'Hara and Wilcox, 1990; McCauley et al., 2000b) indicate that other sea turtles are able to detect sound frequencies in the range of those generated during seismic surveys.

Status Designation

The Atlantic Canada population of leatherback turtle is listed as 'endangered' pursuant to SARA. The leatherback turtle was designated as 'endangered' by COSEWIC in April 1981. Its status was re-examined and confirmed by COSEWIC in May 2001.

2.10.2 Loggerhead Turtle

Distribution, Habitat, Abundance, and Predator and Prey

Loggerhead turtles, *Caretta caretta,* are circumglobal, inhabiting continental shelves, bays, estuaries, and lagoons throughout the temperate and tropical regions of the Atlantic, Pacific, and Indian Oceans. In the western Atlantic, its range extends from Newfoundland to Argentina (NOAA, 2006; Conant et al., 2009). In Atlantic Canada, loggerhead turtles occur in offshore waters from Georges Bank to the Flemish Cap. Temperature is known to be influential to loggerhead distributions. They are encountered in waters greater than 15 ºC, especially between 20-25 ºC (Conant et al., 2009). Nesting occurs primarily in the subtropics with the majority occurring in the western rims of the Atlantic and Indian Oceans. Adult loggerheads make extensive migrations between foraging areas and nesting beaches. Little is known of the geographic origin of loggerheads that have been found in Canadian waters.

The habitat of loggerhead turtles changes throughout their life cycle. Adult females go ashore to lay eggs and seem to prefer steeply sloped, high energy beaches. Young juveniles are typically found among drifting *Sargassum* mats in warm ocean currents. Older juveniles and adults are most often found in coastal waters and tend to prefer a rocky or muddy substrate over a sandy one. They may also be found near coral reefs and venturing into salt marshes, brackish lagoons, and the mouths of rivers (Conant et al., 2009). The turtles are primarily carnivorous but also consume bottom-dwelling invertebrates, such as sponges, jellyfish, mussels, clams, oysters and shrimp. Very little is known of the diet of oceanic juveniles (MarineBIO, 2006; Conant et al., 2009).

There are currently no estimates of loggerhead turtle abundance in Atlantic Canadian waters. Only two loggerhead nesting beaches have greater than 10,000 females nesting per year: South Florida (U.S.) and Masirah Island (Oman). The status of the Oman nesting colony has not been evaluated recently. Total estimated nesting in the U.S. has fluctuated between 47,000-90,000 nests per year over the last decade. Recent analyses of nesting data from the Index Nesting Beach Survey program in southeast Florida show that the population is declining. Similarly, long-term nesting data show loggerhead nesting declines in North Carolina, South Carolina, and Georgia (Conant et al., 2009).

Population Structure Relative to Moratorium Area

Loggerhead turtle bycatch rates are highest in the summer and fall, when the species is believed to be most abundant in Atlantic Canadian waters. Based on limited bycatch data from commercial fisheries, it appears that loggerheads use the warm waters of the Gulf Stream off the Scotian Shelf, Georges Bank, and the Grand Banks as foraging habitat from July through October.

Life History, Location, and Timing

It is estimated that loggerhead turtles live approximately 30-62 years and reach sexual maturity between 14-42 years (Conant et al., 2009). Mating takes place in late March to early June and the eggs are laid throughout the summer. The female excavates a nest and lays up to 125 eggs. A female will nest every 6-21 days, or 2-8 times, during a single nesting season. The eggs incubate for approximately 2 months, depending on the temperature and hatch from April to early September (SFSC, 2009).

Known Vulnerabilities

Loggerheads face threats on both nesting beaches and in the marine environment. The greatest cause of decline and the continuing primary threat to loggerhead turtle populations worldwide is incidental capture in fishing gear. Some studies (O'Hara and Wilcox, 1990; McCauley et al., 2000b) indicate that other sea turtles are able to detect sound frequencies in the range of those generated during seismic surveys.

Status Designation

Loggerhead turtle is not listed pursuant to SARA. In April 2010, they were assessed as 'endangered' by COSEWIC.

2.11 MARINE BIRDS

Eastern Georges Bank is an extremely important area for marine birds throughout the year (Figure 2-100). The peak in bird activity occurs during the summer (Powers and Brown, 1987) when migrants that breed in the South Atlantic, such as the greater shearwater (*Puffinus gravis*), sooty shearwater (*P. griseus*), and Wilson's storm-petrel (*Oceanites oceanicus*), dominate the bird community. Leach's storm-petrels (*Oceanodroma leucorhoa*) are also found on the Bank in the summer when adults are foraging from nesting colonies located in coastal Nova Scotia and along the Gulf of Maine coast. In fall, the shearwaters and storm-petrels are gradually replaced by northern fulmars (*Fulmarus glacialis*), northern gannets (*Morus bassanus*), large gulls, and black-legged kittiwakes (*Rissa tridactyla*), which are migrating from breeding locations in Arctic Canada, Greenland, Newfoundland, and northern Europe.

The bird community remains similar through the winter, although gannets are moving south off the Bank and Alcids are arriving from northern breeding areas. In spring, fulmars remain abundant and gannet numbers again increase as they migrate over the Bank to their breeding colonies. During this time, there is also an influx of arctic-breeding phalaropes to Georges Bank, and shearwaters and storm-petrels arrive from the southern hemisphere. A total of 32 marine bird species from 8 families regularly are found on Georges Bank (Powers and Brown, 1987).

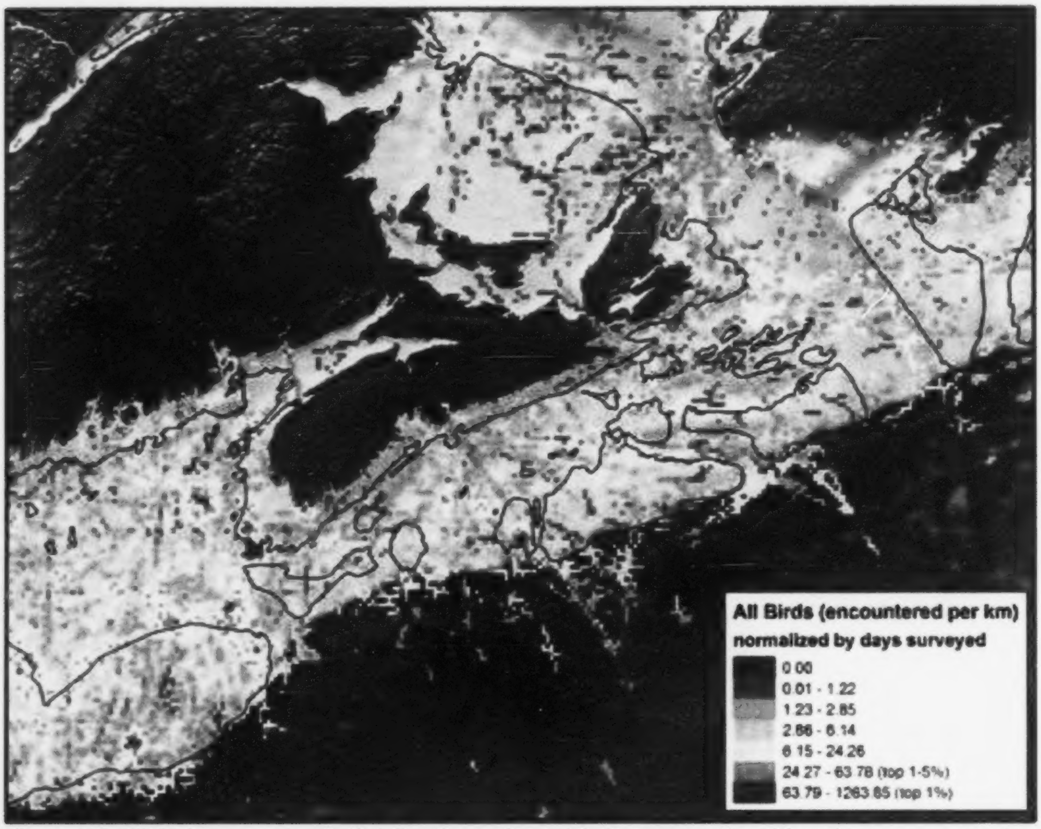


Figure 2-100. Year-round distribution of seabirds normalized by days surveyed.

Marine birds are extremely vulnerable to the effects of oil pollution (Wiese, 2002). Feathers readily absorb oil, decreasing their ability to insulate birds from the cold, and reduce the qualities of waterproofing and buoyancy. A very small amount of oil can lead to death through hypothermia and starvation. Furthermore, birds can die from ingesting petroleum products while preening their feathers. At certain times of the year and, at certain locations, marine birds may concentrate in large numbers, where oil spills could have a large impact on the global population. In addition, delayed maturity and low fecundity in seabirds make recovery from pollution events difficult. Another important threat to seabirds related to offshore oil and gas activities is the potential attraction of birds to artificial light sources on ships and at offshore installations, including light from gas flares. Birds may be killed directly when they fly into the structure or flare or indirectly when they become stranded on the platform. The effects of light attraction on birds, however, have not been well quantified.

Platforms may also act as refuges or artificial reefs, where birds congregate to take advantage of increased food resources, making them more vulnerable to accidental hydrocarbon spills where these installations are located. The Eastern Canada Seabird at Sea (ECSAS) database contains information on pelagic bird surveys from vessels traveling offshore, including data collected between 1965-

1992 for the Programme Integré de Recherche sur les Oiseaux Pélagiques (PIROP) (Brown et al., 1975; Brown, 1986; Lock et al., 1994) and more recent data collected since 2005. Most of the marine bird abundance data for Georges Bank were collected by Manomet Bird Observatory between 1980-1988. The following are descriptions of the most common seabird species sighted on Georges Bank. The timing of the most common species on Georges Bank is highlighted in Table 2-4. Select marine bird species are summarized in the Appendix.

Table 2-4. Seasonal occurrence of seabird species commonly observed on Georges Bank.

	Month											
Species	**J**	**F**	**M**	**A**	**M**	**J**	**J**	**A**	**S**	**O**	**N**	**D**
Greater Shearwater					←	—	—	—	—	—	—	→
Red Phalarope			↔							↔		
Wilson's Storm-Petrel			←	—	—	—	—	—	—	→		
Thick-billed Murre	←	—	—	→								↔
Northern Fulmar	←	—	—	—	—	—	→		←	—	—	—
Herring Gull	←	—	—	—	—	—	—	—	—	—	—	→
Great Black-backed Gull	←	—	—	—	—	—	—	—	—	—	—	→
Black-legged Kittiwake	←	—	—	→						←	—	→
Leach's Storm-Petrel			←	—	—	—	—	—	→			
Sooty Shearwater				←	—	—	—	—	→			
Dovekie	←	—	→							←	—	→
Cory's Shearwater							←	—	—	→		
Northern Gannet			←	—	→					←	—	→
Red-necked Phalarope					←	→				←	→	

2.11.1 Greater Shearwater

Distribution, Habitat, Abundance, and Predator and Prey

Greater shearwaters, *Puffinus gravis*, breed at three main sites in the south Atlantic. These are two very remote islands in the Tristan da Cunha group and on Gough Island. Individuals leave the breeding grounds in April and migrate along the coasts of South and North America to feeding grounds in the north Atlantic. Virtually all of the world's population is thought to spend the non-breeding season in the northwest Atlantic (Brown, 1986). Adults return south to the breeding islands in September, although younger birds likely remain in the area through November.

New tagging studies show birds follow a Z-shaped migration route (Ronconi, 2007), using wind patterns to cross the Atlantic to the west coast of Africa, then south along the African coast before crossing the Atlantic a second time to coastal regions of Argentina. From there, they turn east again, returning to breeding colonies in the central south Atlantic. Greater shearwaters eat fish, squid, and crustaceans from the surface of the water, but are also known to pursue prey underwater. The species has an extremely large range, is very abundant, and the population appears stable.

Population Structure Relative to Moratorium Area

Data collected by the Manomet Bird Observatory from 1980-1988 show that the greater shearwater is the bird species most frequently observed on Georges Bank. The first sightings of this species on the Bank typically occur in May. They remain abundant until November and some observations are recorded through December (Table 2-4). These late observations are most likely of non-breeding or immature birds. Individuals may stay in the vicinity of the Bank for the summer, use the Bank as a stop-over site on their way to other feeding locations in northeast Atlantic, or, because these shearwaters are highly pelagic and can move great distances in a relatively short period of time, they may also move on and off the Bank throughout the season.

Life History, Location, and Timing

Individuals reach sexual maturity between 3-7 years of age. They arrive on their breeding grounds in mid-September and, by November, the female will lay a single egg in a burrow, which is incubated for about 6 weeks. Both adults are involved with the care of the egg and chick. Chicks are fed a regurgitated mixture of fish and stomach oil for approximately 6 weeks, at which time they leave the burrow to take their first flight from the colony. Adults will abandon the colony first in April, while the young will remain into May (Brown, 1986). Activity at the colony is nocturnal. Adult birds show long term fidelity to both their mate and to their nest site. Adult survivorship is high and birds may live up to 20 years.

Known Vulnerabilities

Like most marine birds, greater shearwaters are extremely vulnerable to the effects of oil pollution. In addition, shearwaters are attracted to the lights associated with vessels and offshore platforms, although the impact of this mortality source on the population is not known.

Status Designation

Greater shearwater is not listed pursuant to SARA and has not been evaluated by COSEWIC. It is listed as 'least concern' by the IUCN.

2.11.2 Other Shearwaters

Other shearwaters that have been observed on Georges Bank include the sooty shearwater (*Puffinus griseus*), Manx shearwater (*P. puffinus*), Audubon's shearwater (*P. lherminieri*), and Cory's shearwater (*Calonectris diomedea*). Like the greater shearwaters, sooty shearwaters breed on remote islands in the southern hemisphere and spend their non-breeding season in the north Atlantic. They are found in relatively high numbers on Georges Bank between April and September (Table 2-4). Sooty shearwaters were listed as 'near threatened' in 2004 by the IUCN due to a moderately rapid population decline from the impact of fisheries, the harvesting of its young, and possibly climate change (IUCN, 2010).

The bulk of the Manx shearwater population breeds in the United Kingdom, but a small number (approximately 100 pairs) breed on Middle Lawn Island off southern Newfoundland (Lien and Grimmer 1978). Sightings on the Bank have been recorded during the summer. Audubon's shearwaters breeding in the Caribbean have only rarely been seen on the Bank. Cory's shearwaters breed in the northeast Atlantic and are most common on the Bank in August and into the fall (Table 2-4). These three shearwater species are all listed as 'least concern' by IUCN. The globally-endangered (IUCN, 2010) Bermuda petrel (*Pterodroma cahow*) moves north from breeding areas in Bermuda, following warm waters on the western edges of the Gulf Stream. It has been sighted infrequently in waters adjacent to Georges Bank.

2.11.3 Red Phalarope

Distribution, Habitat, Abundance, and Predator and Prey

Red phalaropes, *Phalaropus fulicarius,* breed in the circumpolar Arctic, primarily on coastal tundra north of 60°N (Tracy et al., 2002). The species migrates over the open ocean to winter in south temperate and subtropical/tropical waters. In spring, individuals breeding in the eastern Canadian Arctic are believed to travel from west and southwest Africa across the Atlantic, over Georges Bank and the Scotian Shelf, before arriving into Canadian Arctic waters in early to mid-June (Brown, 1986). They are found mostly along ocean fronts, associated with high concentrations of zooplankton (Tracy et al., 2002). On the breeding grounds, red phalaropes are insectivorous in wetlands. At sea, marine copepods and amphipods are their main prey choice, but diet may also include fish eggs, larval fish, mysids, and euphausiids (Tracy et al., 2002). Overall, numbers across their range appear to be declining, although abundance estimates are extremely difficult to obtain. Surveys in the eastern-central Canadian Arctic indicate a dramatic decline (76%) between 1975-76 and 1994-95 (Tracy et al., 2002).

Population Structure Relative to Moratorium Area

Data show that the red phalarope was the second most abundant bird species observed on Georges Bank from 1980-1988. They typically arrive on the Bank from the Mid-Atlantic Bight in May where they remain for the month to feed before moving to their breeding grounds in the eastern Canadian Arctic (Table 2-4). After the breeding season, large flocks stage in the Bay of Fundy in August and September and then move either southeast across the Atlantic or south along the east coast of North America (Tracy et al., 2002). They are common on Georges Bank during October (Table 2-4). They appear to be less common on the Bank during their southward migration in the fall compared to their northward migration in the spring.

Life History, Location, and Timing

Red phalaropes likely begin breeding as yearlings (Tracy et al., 2002). Females typically lay four eggs in one or two clutches a season. The male incubates the eggs for about 20 days and, alone, broods the young through the first 12 days after hatching. Chicks are precocial at hatching, meaning that they hatch fully covered with down and leave the nest to find food on their own the same day of hatch. Males are associated with the young for up to 12 days and young are able to fly at about 18 days post-hatch (Tracy et al., 2002). This species is usually monogamous within a single breeding season, although females are known to mate with multiple males. No information exists on life span and survivorship.

Known Vulnerabilities

As with most other marine bird species, red phalaropes are highly susceptible to oil pollution. An oil spill coinciding temporally and spatially with concentrations of this species on Georges Bank may be expected to have a large impact on the global population.

Status Designation

Red phalarope is not listed pursuant to SARA and has not been evaluated by COSEWIC. It is listed as 'least concern' by the IUCN.

2.11.4 Other Phalaropes

Red-necked phalaropes, *P. lobatus*, also occur on Georges Bank during their spring and fall migration, slightly later than red phalaropes and in smaller numbers. They migrate primarily along the coast or offshore, but also overland. Historically, the western Bay of Fundy was an important fall staging area for huge densities of red-necked phalaropes (up to 20,000 birds km^{-2}), although numbers have been declining since the mid-1980's (Rubega et al., 2000). It is not known whether this decline represents a change in population size or whether the phalaropes are staging elsewhere in response to changing ocean conditions. The red-necked phalarope has been identified by COSEWIC as a high-priority candidate for status report production. It is listed as 'least concern' by the IUCN.

2.11.5 Wilson's Storm-Petrels

Distribution, Habitat, Abundance, and Predator and Prey

Like the greater and sooty shearwaters, Wilson's storm-petrels, *Oceanites oceanicus,* breed in the southern hemisphere and spends the non-breeding season in the north Atlantic. They migrate between hemispheres in all oceans, although they are uncommon in the Pacific. In the Atlantic, the main northward migration occurs over the western sector (Harrison, 1988), and birds typically arrive on Georges Bank by May (Table 2-4). They begin their return to southern breeding grounds in August, but are observed on the bank into October. Non-breeders may remain in the north Atlantic throughout the year (Harrison, 1988).

Wilson's storm-petrels are often observed at sea in large flocks reaching several thousands during migration. They feed by dipping their feet into the water, capturing prey from the surface. They feed primarily on amphipods, *Euphausia*, squid, and fish. They readily follow ships, attracted by the offal, and whales and dolphins. Wilson's storm-petrels are numerous (several million pairs) and wide ranging. Although very difficult to assess, there is no evidence to suggest large population changes in this species.

Population Structure Relative to Moratorium Area

Wilson's storm-petrels are observed on Georges Bank from May to October (Table 2-4). They are highly pelagic and may fly great distances in a relatively short period of time. Movement on and off the Bank throughout the summer is likely.

Life History, Location, and Timing

Age of first breeding is estimated to be 5 years for the Wilson's storm-petrel. They nest in cavities and in tunnels excavated by the birds under boulders. Adults usually enter and leave the nest site at night to minimize their predation risk. Just one egg is laid per nest, and both parents incubate the egg (5-6 weeks) and feed the chick (6-7 weeks). The birds return to their colonies in Antarctica in November to December and lay their egg in December to January (Brown, 1986). Fledging and dispersal from breeding colonies begins in April. Typical of many seabirds, adult survivorship is high, and birds are relatively long lived.

Known Vulnerabilities

Wilson's storm-petrels are vulnerable to oil pollution, and their attraction to lights on platforms and vessels kills an unknown number of individuals. The impact of this source of mortality on the population is not known.

Status Designation

Wilson's storm-petrel is not listed pursuant to SARA and has not been evaluated by COSEWIC. It is listed as 'least concern' by the IUCN.

2.11.6 Other Storm-Petrels

Leach's storm-petrels, *Oceanodroma leucorhoa,* are also relatively abundant on Georges Bank from March through September (Table 2-4). Unlike the Wilson's storm-petrel, this species breeds in the northern hemisphere. In the northwest Atlantic, they breed on islands from southern Labrador to Massachusetts. The largest breeding population in the world is thought to be on Baccalieu Island in Newfoundland, where some 3.5 million pairs are estimated to breed (Sklepkovych and Montevecchi, 1989). The breeding season for Leach's storm-petrels extends from late May through September. They lay a single egg in a burrow and both parents incubate the egg and raise the chick. Adults eat a variety of plankton and nektonic species, including fish, cephalopods, crustaceans, and jellyfish (Huntington et al., 1996). They concentrate at fronts and eddies, where upwelling brings prey to the surface, and may forage more than 200 km from breeding colonies (Huntington et al., 1996). Like the Wilson's storm-petrel, this species is vulnerable to oil spills and significant mortality may occur when individuals are attracted to the lights and flares associated with oil exploration and production activities. It is listed as 'least concern' by the IUCN.

2.11.7 Thick-Billed Murre

Distribution, Habitat, Abundance, and Predator and Prey

Thick-billed murres, *Uria lomvia,* have a circumpolar arctic and boreal distribution. In Atlantic Canada, they breed in southern Labrador, as well as in small numbers on the north shore of the Gulf of St. Lawrence and in Newfoundland. The largest colonies are in the High Arctic. Murres that breed in the eastern Canadian Arctic, winter mainly in the offshore of Newfoundland and Labrador. Smaller numbers winter in the Gulf of St. Lawrence, Scotian Shelf, Bay of Fundy, and Georges Bank. They are found mainly in continental shelf waters, not commonly close inshore (Brown, 1986). Like all species in the family Alcidae, thick-billed murres pursue their prey underwater using their wings. Typical dive depth is about 20 m, but depths as great as 200 m have been recorded (Gaston and Hipfner, 2000). Adults prey mainly on midwater schooling fish such as cod, smelt, and sand lance, but also on crustacea, benthic fishes, shrimps, squid, and annelids (Gaston and Hipfner, 2000). Numbers in the eastern Canadian Arctic are believed to be stable or slightly increasing, although numbers in Greenland decreased substantially from the 1940s to the 1980s as a result of hunting (Gaston and Hipfner, 2000).

Population Structure Relative to Moratorium Area

Thick-billed murres breeding in the Canadian Arctic and western Greenland move south to Newfoundland waters, arriving anytime between October and December. Smaller numbers winter farther south off the coast of the northeastern U.S. Return migration begins as early as March. Individuals typically reach their breeding grounds by mid-May. Data show thick-billed murre sightings on Georges Bank from December through May (Table 2-4).

Life History, Location, and Timing

Thick-billed murres typically breed for the first time at age 4-5 years. They nest on cliff ledges and sometimes in caves or crevices (Gaston and Hipfner, 2000). One egg is laid and both the male and female take turns to incubate for about 5 weeks. Both parents also care for the young, returning to feed 2-6 times a day for about 3 weeks. Although not fully developed, the chick departs the colony at this time by jumping from the nest site into the sea. It is the male parent that leaves with the chick, feeding it on the surface of the ocean for a month or more. In the Atlantic, the breeding season begins in late May and continues through early September. Adult survivorship is 90%, and band recoveries have shown birds living in excess of 25 years (Gaston and Hipfner, 2000).

Known Vulnerabilities

Like all members of the family Alcidae, thick-billed murres are extremely vulnerable to the effects of oil pollution as they spend most of their time on the surface of the water. The species often congregates in large numbers and will dive underwater rather than fly if disturbed. High adult survival rates and low rates of fecundity mean population recovery from oil spills is difficult. Wiese (2002) estimates several tens of thousands are killed every year off the coast of Newfoundland from chronic oil pollution. Population declines over the next 20 years are likely if human-induced mortality remains at current levels (Wiese, 2002).

Status Designation

Thick-billed murre is not listed pursuant to SARA and has not been evaluated by COSEWIC. It is listed as 'least concern' by the IUCN.

2.11.8 Other Alcids

Other members of the family Alcidae observed on Georges Bank include the common murre (*U. aalga*), dovekie (*Alle alle*), Atlantic puffin (*Fratercula arctica*), and razorbill (*Alca torda*). Most of the common murres in Atlantic Canada breed in eastern Newfoundland (Brown, 1986) and are observed on Georges Bank in the winter. As common murres are difficult to tell apart from thick-billed murres during at-sea surveys, the ratio of thick-billed to common murres in our data may not be representative of the true distribution. Powers and Brown (1987) suggest common murres are more abundant on Georges Bank than thick-billed murres. Dovekies are also observed on the Bank during their non-breeding season, departing for breeding colonies in Greenland in late March, returning again in early October (Table 2-4). Over 12 million pairs of Atlantic puffins are estimated to breed in the North Atlantic (Brown, 1986). During the winter, they are widely dispersed and well offshore, but only occasionally observed on Georges Bank. Razorbills breed in the boreal and low Arctic regions of the North Atlantic (Brown, 1986) and have been observed in small numbers on Georges Bank and inshore from January through May. All of the alcid species are listed as 'least concern' by the IUCN.

2.11.9 Northern Fulmar

Distribution, Habitat, Abundance, and Predator and Prey

Northern fulmars, *Fulmarus glacialis,* are related to the petrels and shearwaters and are abundant in both Alaska and the Canadian Arctic. The majority of fulmars in North America breed in the eastern Canadian Arctic above 65°N (Hatch and Nettleship, 1998). They are widely dispersed throughout the Atlantic during the non-breeding season, but major concentrations exist on the Grand Banks off Newfoundland. They are commonly found over deep, cold waters in low-Arctic regions, and show a preference for shelf break habitats (Hatch and Nettleship, 1998). Northern fulmars arrive at breeding colonies in the High Arctic in late April or early May, and typically leave by mid-October.

Northern fulmars are omnivorous, eating fish, cephalopods, zooplankton, offal, and carrion (Hatch and Nettleship, 1998). They have been observed feeding at the ice edge on macrozooplankton, and in areas of local upwelling. This species is known to associate with black-legged kittiwakes during the chick-rearing period, and also with gray whales (Hatch and Nettleship 1998). They pick their prey from the surface of the water, but may also plunge under the surface and pursue their prey. Fulmars are well known for following fishing vessels and scavenging offal. The Atlantic population of northern fulmars has expanded in both range and number over past 200 years (Hatch and Nettleship, 1998). It is believed that the modern trawl fishery may be responsible for the expansion, although oceanographic changes may also play a role. At present, the Atlantic population appears stable.

Population Structure Relative to Moratorium Area

Data show sightings of northern fulmar on Georges Bank throughout the year except during August (Table 2-4). They are common from January to March.

Birds arriving earlier and those departing later are most likely either immature birds or non-breeders.

Life History, Location, and Timing

Northern fulmars delay breeding until perhaps as old as 5 years. In Greenland, immature birds may remain at sea for three years before visiting the breeding colony. Breeding phenology is largely tied to environmental conditions, but in the Atlantic, birds typically arrive on the colony in mid to late-April (Hatch and Nettleship, 1998). One egg is laid on a slope or cliff edge nest, both parents incubate for almost 50 days, and both parents feed the chick for another 50 days. When chicks fly from the nest they are independent of their parents. Most leave the colony by late September to scatter widely over the north Atlantic, although some may remain close to breeding colonies for much of the year (Hatch and Nettleship, 1998). Adults show strong fidelity to breeding sites. They have high annual survivorship (95%) and may live in excess of 30 years (Hatch, 1987).

Known Vulnerabilities

As with most other marine bird species, northern fulmars are highly susceptible to oil pollution. The propensity of fulmars to concentrate in large numbers makes them vulnerable to pollution events, including oil spills and dumping of plastics. Their delayed maturity and low fecundity make recovery from pollution events difficult.

Status Designation

Northern fulmar is not listed pursuant to SARA and has not been evaluated by COSEWIC. It is listed as 'least concern' by the IUCN.

2.11.10 Herring Gull

Distribution, Habitat, Abundance, and Predator and Prey

Herring gulls, *Larus argentatus*, are one of the most recognizable seabirds in Atlantic Canada. They have a circumboreal breeding range, and in eastern North America, breed along the Atlantic coast from Baffin Island to Cape Hatteras. During the winter, these birds are distributed fairly continuously along the Atlantic coast, and show a strong association with open fresh or salt water (Pierotti and Good, 1994). They breed predominantly on predator-free islands, but are also known to nest in cities or on rooftops near water (Pierotti and Good, 1994). Some individuals remain around breeding colonies in the winter, while others move south to tropical coastlines. These birds are most common close to land, although they are seen regularly offshore outside the breeding season (Brown, 1986). Large numbers of juveniles are known to associate with humpback whales in the Gulf of Maine and the Scotian Shelf when fish are driven to the surface (Pierotti, 1988).

Herring gulls are generalist predators, feeding on pelagic and intertidal marine invertebrates, fish, insects, other seabirds and their eggs. They opportunistically scavenge on carrion and human garbage. In Newfoundland, herring gulls primarily feed on mussels and other seabird species such as the Leach's storm-petrels during the pre-laying and incubation periods, then switch to capelin and other fish species when the chicks hatch (Pierotti and Good, 1994). Herring gulls are also known to scavenge at fishing vessels. Numbers of North American herring gull populations have increased significantly since 1900s as a result of decreased persecution on nesting grounds, increased access to refuge, and supplementary feeding at fishing vessels. Populations in eastern Canada, Maine, and Massachusetts, however, now appear to be on the decline (Pierotti and Good, 1994; Cotter et al., 2010), perhaps as a result of decreased fishing activity and increased competition from great black-backed gulls.

Population Structure Relative to Moratorium Area

Herring gulls are most common off the northeastern U.S. from October to May, with numbers peaking in March. There are also reports of a major offshore movement of herring gulls in the northeastern U.S. and Canadian Maritimes in the late fall and winter (Brown 1986, Pierotti and Good 1994). Herring gulls are observed on Georges Bank throughout the year (Table 2-4).

Life History, Location, and Timing

Birds first breed at 4-5 years of age. In Atlantic Canada, herring gulls typically lay their clutch of 2-3 eggs from mid-April to mid-May, but laying may continue through June (Brown, 1986). Both parents incubate for about a month, and both parents feed the chicks for 6-8 weeks. Young-of-the-year birds begin to leave the colony in the last half of July. Most adults remain near breeding colonies throughout the year, while young birds migrate to the southern portion of their range. Juvenile survivorship is relative low (50%) but, once they reach breeding age, survival estimates are closer to 90% (Pierotti and Good, 1994).

Known Vulnerabilities

As with most other marine bird species, herring gulls are susceptible to oil pollution at pelagic foraging areas. Their delayed maturity and low fecundity make recovery from pollution events difficult.

Status Designation

Herring gull is not listed pursuant to SARA and has not been evaluated by COSEWIC. It is listed as 'least concern' by the IUCN.

2.11.11 Great Black-backed Gull

Distribution, Habitat, Abundance, and Predator and Prey

Great black-backed gulls, *Larus marinus,* occur only in the North Atlantic, and breed from North Carolina to Hudson Strait, with small populations scattered inland to the Great Lakes and west to northern Europe (Brown, 1986). Like the herring gulls, great black-backed gulls are most common close to land, but are regularly observed offshore outside the breeding season. Typically, they occur farther offshore than the herring gulls, and breed farther north. Birds breeding in southern Newfoundland move 50-100 km offshore to deeper water in late August, where they remain until April (Good, 1998). Different populations show varying degrees of migratory behaviour. Populations from Nova Scotia and New England tend to remain in the vicinity of breeding colonies, whereas birds from more northerly sites disperse southward (Good, 1998). Their wintering grounds extend as far south as Florida. During winter, they are often associated with coastal communities, roosting near ports, docks, dumps, and at estuaries (Good, 1998).

Great black-backed gulls are generalist predators, which prey on fish, marine invertebrates, mammals, insects, and other seabirds and their eggs. They also scavenge on human garbage, carrion, and are known to forage at offal from fishing vessels. At sea, they are often observed in small foraging groups. On Georges Bank, adults and juveniles have been observed feeding in pairs, and associated with feeding bluefin tuna (Pierotti, 1988). There is a recent increasing trend in great black-backed gull abundance as their range is expanding southward (see Good, 1998). Three censuses of gulls in Nova Scotia (1971, 1987, and 2002), however, show a 74% increase between 1971 and 1987, and a subsequent 31% decline between 1987 and 2002 (Cotter et al., 2010).

Population Structure Relative to Moratorium Area

In spring, immature birds and subadults are common in the shelf waters in the Gulf of Maine, Georges Bank, and southern New England. Band recoveries indicate that a significant proportion of great black-backed gulls winter in the Canadian Maritimes and northeastern U.S., on Georges Bank, and throughout the Gulf of Maine (Good, 1998).

Life History, Location, and Timing

Great black-backed gulls begin breeding at between 4-5 years of age. Females lay between 2-3 eggs, and both parents incubate and feed the chicks. Incubation lasts about a month, and chicks take their first flight at 45 days (Good, 1998). They don't typically leave the nest territory for another week or more, and some young will remain with one or both parents for several months after fledging. Fall dispersal from breeding colonies occurs mainly from September-October, and the return migration from March-April (Good, 1998). Like most seabirds, adult survivorship is relatively high.

Known Vulnerabilities

As with most other marine bird species, great black-backed gulls are susceptible to oil pollution at pelagic foraging areas. Their delayed maturity and low fecundity make recovery from pollution events difficult.

Status Designation

The great black-backed gull is not listed pursuant to SARA and has not been evaluated by COSEWIC. It is listed as 'least concern' by the IUCN.

2.11.12 Black-legged Kittiwake

Distribution, Habitat, Abundance, and Predator and Prey

Black-legged kittiwakes, *Rissa tridactyla,* are one of North America's most widely distributed gulls. They have a circumpolar breeding distribution, although most breed in the Arctic and Subarctic. In Atlantic Canada, the largest colonies are found in eastern Newfoundland and the Gulf of St. Lawrence. During the breeding season, they remain relatively close to the coast, foraging within 50 km of the colony at upwellings or oceanic fronts (Baird, 1994). During migration, they are distributed offshore, often along the edge of sea ice. Black-legged kittiwakes winter from Newfoundland south to Georges Bank, feeding over a variety of water depths.

Black-legged Kittiwakes are piscivorous, catching their prey at the surface of the water. Prey species include capelin, sand lance, arctic cod, and pollock (Baird, 1994). They also feed on some invertebrates. The species is known to scavenge at fishing vessels. There is some indication that in the western Atlantic, the numbers of black-legged kittiwakes have increased. They have expanded their range south from Newfoundland to locations off Cape Breton Island, Nova Scotia, and into the Bay of Fundy and the Gulf of St. Lawrence coast in New Brunswick. In contrast, numbers at the largest colonies in Newfoundland appear to be in decline (Cotter et. al., 2010).

Population Structure Relative to Moratorium Area

Black-legged kittiwakes are most common off New England in January to March (Brown, 1986), although data suggest they occur on Georges Bank from October to April (Table 2-4). Returns from banding studies show that these birds are coming from breeding areas in Greenland, Iceland, and in the eastern Atlantic (see Brown, 1986), and are comprised of both adults and immature birds.

Life History, Location, and Timing

Like most seabirds, adults delay breeding until 4 or 5 years. Birds breeding in Newfoundland may begin nest-building as early as February and most young have fledged from the nest by mid- to late September (Baird, 1994). Their nests are built on cliff ledges and the females typically lay two and occasionally three eggs. Both adults take turns incubating the egg for approximately 25 days, and chicks are fed by both the male and female until they leave the nest between 35 and 50 days later, depending on their condition (Baird, 1994). Adults show strong fidelity to breeding sites. They have high annual survivorship (between 80-90%) and are long lived.

Known Vulnerabilities

As with most other marine bird species, black-legged kittiwakes are susceptible to oil pollution. An oil spill in Alaska was estimated to have killed thousands of kittiwakes. The spill also negatively impacted subsequent breeding productivity by destroying their prey base (Baird, 1994). Their delayed maturity and low fecundity make recovery from pollution events difficult.

Status Designation

The black-legged kittiwake is not listed pursuant to SARA and has not been evaluated by COSEWIC. It is listed as 'least concern' by the IUCN.

2.11.13 Northern Gannet

Distribution, Habitat, Abundance, and Predator and Prey

Northern gannets, *Morus bassanus,* are restricted to continental shelf waters on both sides of the Atlantic. In North America, they breed in just 6 colonies, 3 in Quebec, and 3 off the coast of Newfoundland. They breed in very dense colonies within foraging distance from their principal prey, the herring and mackerel, although adults may travel up to 500 km from the colony to forage (Mowbray, 2002). Post-breeding gannets forage in the Gulf of St. Lawrence, Strait of Belle Isle, nearshore waters off Labrador, and the east coast of Newfoundland before moving farther south for the winter (Mowbray, 2002). In winter, birds are more dispersed but remain mainly over shelf waters. In North America, their non-breeding range extends from New England south to Florida, and west along the Gulf of Mexico coast to Texas. In general, adults remain farther north than subadults during the winter (Mowbray, 2002).

Northern gannets feed primarily on surface-schooling fish including mackerel, herring, and capelin. To feed, they fly to a height of 10-40 m, turn, then use gravity to drop and plunge through the surface of the water, known as plunge-diving. They descend to a depth of 3-5 m, or even deeper if they swim to pursue their prey (Mowbray, 2002). Northern gannets were heavily persecuted before legal protection by the Migratory Birds Convention Act, and suffered declines due to the effects of dichlorodiphenyltrichloroethane (DDT) in the last century (Mowbray, 2002). As a result of legal protection and restrictions on the use of certain chemical substances, gannet populations in Atlantic Canada have increased dramatically (Chardine, 2000).

Population Structure Relative to Moratorium Area

Northern gannets are present on their breeding sites in the western Atlantic from about March through November. Southward migration begins in September, and by early to mid-October, large numbers of juveniles are on Georges Bank and adjacent waters (Veit and Petersen, 1993). Juveniles and subadults tend to travel farther south than adult birds, and remain longer in the wintering grounds than the adults. Adults appear to winter off the coast of New England. Northern gannets begin their northward migration in early March. Data show northern gannets on Georges Bank from March through May, travelling north to breeding colonies, and then again from October through December as they make their way south for the winter (Table 2-4).

Life History, Location, and Timing

Gannets remain at sea all year during their first 3 years. Age at first breeding is typically 4 or 5 years. At their main breeding colony in Newfoundland, Bonaventure Island, each breeding female lays a single egg in mid-May and the chick hatches in early July. Both adults take turns incubating the egg and feeding the chick. The average incubation period on Bonaventure Island is 44 days, and chicks fledge at 90 days, on average (Mowbray, 2002). The young may not leave the colony until October, or later (Brown, 1986). The peak southward migration passes Long Island, New York, in November, and birds begin to arrive in their wintering grounds in December (Brown 1986). Adults show strong fidelity to breeding sites, they have high annual survivorship, and an average life expectancy of 16 years (Mowbray, 2002).

Known Vulnerabilities

Northern gannets are not affected by oil spills to the degree that many other seabirds are due to their foraging method. They would be impacted by oil pollution, however, if that oil were to negatively affect their prey base. Their delayed maturity and low fecundity make recovery from pollution events difficult.

Status Designation

Northern gannet is not listed pursuant to SARA and has not been evaluated by COSEWIC. It is listed as 'least concern' by the IUCN.

2.11.14 Other Laridae

Several other species from the family Laridae are observed on Georges Bank, including the ring-billed gull (*Larus delawarensis*), Iceland gull (*L. glaucoides*), glaucous gull (*L. hyperboreus*), and laughing gull (*Leucophaeus atricilla*). Ring-billed gulls breed throughout Atlantic Canada except in Nova Scotia. Small numbers are observed on the Bank during the spring and fall migration when the birds are moving between their breeding grounds and wintering areas along the eastern coast of the U.S. Arctic-breeding Iceland and glaucous gulls have occasionally been sighted on the Bank during the non-breeding season. Laughing gulls also are observed occasionally on the Bank during the winter before migrating south to breeding grounds located from central Maine to Georgia. Bonaparte's gulls (*L. philadelphia*) breed on lakes in the boreal forests of western Canada and Alaska, and are infrequently sighted on Georges Bank during the non-breeding season. All these gull species are more typically observed along the coastline than locations far from shore. They are all listed as 'least concern' by the IUCN.

Common terns (*Sterna hirundo*) are also occasionally observed on Georges Bank, while arctic terns (*S. paradisaea*) are less frequently sighted. Both species tend to occur closer to the coastline. They breed at colonies in coastal Nova Scotia and along the Gulf of Maine coast, and have been observed over the Bank during the spring, before the breeding season. Common terns spend their winter mainly along the coasts of Central and South America, while the arctic terns winter principally around Antarctica. The roseate tern (*S. dougallii*), which breeds at relatively few coastal locations from Long Island, New York to northern Nova Scotia, is listed as 'endangered' pursuant to SARA. This is a primarily coastal species and records on Georges Bank are rare. All three tern species are listed as 'least concern' by the IUCN.

2.11.15 Other Birds

A number of other marine birds have been observed on Georges Bank. Common loons (*Gavia immer*) cross the Bank in May and November when moving between breeding and non-breeding locations in northeastern North America. Three species of jaegers, all circumarctic breeders, have also been observed on the Bank, mainly in the spring and fall. Of these, pomarine jaegers (*Stercorarius pomarinus*) are the species most frequently sighted. Parasitic jaegers (*S. parasiticus*) are more commonly observed along the coast, and long-tailed jaegers (*S. longicaudus*) are only rarely recorded over the Bank (Powers and Brown, 1987). Great skuas (*S. skua*), which breed in the eastern North Atlantic, are sighted throughout the year, but are most common from October to March (Powers and Brown, 1987). South polar skuas (*S. maccormicki*) breed in the southern hemisphere, but have been observed on Georges Bank from May through October (Powers and Brown, 1987). These species are all listed as 'least concern' by the IUCN.

2.12 STATE OF KNOWLEDGE

While broad-scale understanding of the major physical drivers operating on Georges Bank have not changed since the previous review in 1999, there is a better understanding of the finer-scale details of how these processes operate, how they influence natural chemical and biological processes (e.g. nutrient flux, primary production and distribution of zooplankton), and how they might influence particle dispersion. The ability to observe and model these processes has also improved. There has been some investigation of how the chemical and physical environment of Georges Bank has changed over the past few decades (e.g. changes in surface temperatures and stratification), although the implications for the ecosystem as a whole are still being explored.

Georges Bank is known to be a very productive ecosystem, having high levels of primary production with comparatively low levels of zooplankton. Since 1999, advances have been made in the understanding of the role of microbes in this ecosystem (which assist with recycling of nutrients), as well as of the distribution, trends, and interactions of zooplankton. Changes in production and species composition have also been noted, with indications of a decline in spring cholorophyll and changes in zooplankton communities in response to the changing influences of water masses. Significant research since 1999 has also been conducted on corals in the Northeast Channel. In 2002, the Northeast Channel Coral Conservation Area was created to protect high densities of large, branching gorgonian corals.

There have been numerous new assessments of fish stocks present in the Georges Bank moratorium area, some of which are increasing after periods of lower abundance (e.g. haddock, yellowtail, herring), while others appear to remain at low levels (e.g. cod). There have also been new assessments of scallops, lobster, and Jonah crab, which indicate that scallop and lobster populations are increasing. Since 1999, there have been COSEWIC assessments or re-assessments of at least 12 species found on Georges Bank. New assessments and research have been conducted for both loggerhead and leatherback turtles since 1999, which help to provide new information on their use of Georges Bank and its surrounding areas. Seals are an increasing concern in the Gulf of Maine, particularly by fishermen, though limited work has been done specifically for Georges Bank.

Although the biological resources are well described and many of the linkages to the physical environment and other trophic levels have been identified, there remain many areas of incomplete understanding. Some new work has been done on the associations between groundfish and benthic habitats, but much is still unknown about specific habitat requirements and the locations of key feeding and spawning habitats of numerous species found on Georges Bank. For example, little is known about the breeding areas of fin whales and sei whales, leatherback turtles, black dogfish, and monkfish, while knowledge of the diets of cusk and juvenile loggerhead turtles are incomplete. One exciting new discovery, however, was the identification of a porbeagle shark pupping ground on Georges Bank.

There have been scientific advances in our understanding of the movements of many fish species in relation to Georges Bank, based on ongoing tagging studies, as well as advances in the understanding of the transport of larvae. Understanding of stock structure for many species, however, particularly the relationship between fish and invertebrates in Canadian and U.S. waters, is limited. The migration pattern of northern and southern components of northern shortfin squid, for example, is unknown. Similary, the stock structures of lobsters, Jonah crab, Atlantic halibut, witch flounder, and bluefin tuna are not well defined.

2.13 CONCLUSION

Georges Bank is a broad submarine bank located between the southwestern tip of Nova Scotia and Cape Cod, Massachusetts. The most southwesterly edge of Georges Bank is bounded at the Great South Channel and its northeasterly edge is bounded at the Northeast Channel. The northern boundary separating this biogeographic area from the rest of the Gulf of Maine extends in a northeasterly direction from the Great South Channel. The Georges Bank moratorium area is a diverse and productive marine ecosystem that has been the focus of many research initiatives over the past few decades. This has resulted in a good understanding of the individual physical and biological components of the system. There remains, however, many unanswered questions relating to the complex relationships between components, trophic dynamics, the interannual variations of populations, and the linkages with physical and chemical characteristics of the system. Predicting the response of the system to perturbations may be difficult.

The topographic and hydrographic features of the Bank result in high primary production, which in turn fuels high levels of productivity and fish biomass. For example, the strong tidal forces on the Bank, coupled with topographic features, result in the establishment of an anticyclonic gyre that result in the partial retention of planktonic organisms. In addition, the fronts and gyre around the Bank facilitate the upwelling of nutrients onto the Bank and into the photic zone, leading to enhanced plankton production which supports a diverse food web. Perturbations that affect the timing and rate of primary and zooplankton production can affect the recruitment success of commercially-important species that are dependant on such production.

Georges Bank receives cold coastal waters through the Gulf of Maine from the Scotian Shelf and warm slope water through the Northeast Channel. With influences from both subpolar and subtropical water, the Bank acts as both the northern limit for many warm water species (e.g. bottlenose dolphin, and red crab) and the southern limit for many cold water species (e.g. sei whale). This results in a high level of diversity.

Georges Bank also can serve as a source of organisms for surrounding areas. Strong, episodic forcing (e.g. winter storms) and warm-core ring entrainments result in an exchange of water and associated particles with surrounding water bodies, such as Browns Bank, and represent mechanisms for exchange from the Bank. For example, it is not known what percentage of lobster larvae is retained by the partial gyre of Georges Bank, although pelagic lobster larvae have been observed on the northern edge of the Bank, indicating some degree of off-Bank movement.

A distinctive characteristic of the Bank is its populations of bottom organisms, which are dominated by large filter feeders (e.g. scallops) that make up three-quarters of the biomass of the large, bottom dwelling organisms found in the area. Georges Bank also provides permanent or temporary habitat for many of the life stages of various fish, invertebrate, seabird, marine mammal, and turtle species, including bluefin tuna, swordfish, shearwater or phalaropes, corals and other benthos, as well as several species that have been listed or are being considered for listing pursuant to SARA. With the high diversity of organisms, Georges Bank is used year round as a feeding ground, spawning/nursery area, and/or migrations corridor for numerous species (see Appendix). For example, leatherback and loggerhead turtles commonly forage on the Bank in the summer and fall, while whales reach peak abundance in the spring and summer. The Bank is an important nursery ground for juvenile cod and haddock, but also acts as a migratory corridor for the North Atlantic Right Whale during its annual migration from wintering areas further south to feeding areas in Canadian waters.

Last, seabirds are abundant on Georges Bank at all times of the year, although very few birds breed there. Georges Bank is an important destination for staging migrants, during their northward and southward movements, and also for over-wintering species.

3.0 POTENTIAL INTERACTIONS ASSOCIATED WITH OFFSHORE PETROLEUM ACTIVITIES

3.1 PETROLEUM POTENTIAL OF GEORGES BANK

It is difficult to accurately estimate the quantity and types of hydrocarbon resources in the Georges Bank moratorium area. The most recent seismic data was acquired in the early 1980s, and is difficult to interpret due to poor resolution, spatial distortion, and displacement (USMMS, 2000). New seismic data acquisition and processing, both regional two-dimensional (2D) and local three-dimensional (3D), would generate higher resolution images of the geological formations to better map and understand the geology, as well as more accurately assess the hydrocarbon resources in the area (Kidston et al., 2005).

From the 1960s to the early 1980s, approximately 63,000 km of 2D seismic data were collected over the Georges Bank area, of which two thirds were located on the U.S. side of the Bank (Kidston et al., 2005). In 1984, JEBCO Seismic Ltd. acquired 6800 km of data in the area that later became part of the Georges Bank Moratorium area. It remains the most recent seismic dataset available. In contrast, the Canada-Nova Scotia Offshore Petroleum Board has reported that since the early 1960s more than 495,000 km of 2D and 32,000 km^2 of 3D seismic data have been collected in the remaining waters off the coast of Nova Scotia alone.

The Geological Survey of Canada (GSC) undertook resource assessments of the Georges Bank region in 1978 and 1979 based on existing, very limited, and poor quality geophysical data. These reports remain confidential, but a single page summary of the two studies was included in the GSC's 1984 petroleum resource assessment of the Scotian Shelf (Proctor et al., 1984). The authors theorized that the geology and hydrocarbon plays of Georges Bank were similar to those in the similar-sized and gas-rich Sable Subbasin. For the Georges Bank region, the authors' "high confidence" estimate was 62.9 million barrels of oil, the "average confidence" estimate was 1.06 billion barrels (Bbbls) of oil, and the "speculative" estimate was 2.2 Bbbls of oil. For natural gas, the "high confidence" estimate was 1.3 trillion cubic feet (Tcf), the "average confidence" estimate was 5.3 Tcf, and the "speculative" estimate was 10.8 Tcf. It should be noted that these estimates are not considered reliable and should not be compared to more recent estimates of proven reserves in other areas.

Reservoirs of Georges Bank were expected in lower Cretaceous and upper Jurassic age deltaic sandstones located at depths between 2700-4900 m, as those below a depth of 4100 m would be over pressured (USMMS, 2000). Instead of the predicted reservoir-quality, porous carbonates, the ten U.S. wells drilled in the late-1970s to early-1980s encountered low porosity limestones such as micrites, wackestones, and packstones, while high velocity volcanics and halite/anhydrites were responsible for some of the interpreted "bright spots" that in certain cases indicate the presence of hydrocarbon-bearing reservoirs (USMMS, 2000; Kidston et al., 2005). According to USMMS (2000), the source rocks encountered in the wells drilled on the U.S. portion of Georges Bank were poor over the thermal maturity depth range (2440-6700 m). No significant hydrocarbon discoveries or shows were encountered in any of the wells. No test wells have been drilled on the Canadian side of the Bank. The existing seismic data, however, suggests that the geology is different in the Canadian portion of the Bank, with a better potential for possible hydrocarbon generation and trapping.

It is important to note that all petroleum resource assessments of Canada's portion of Georges Bank were completed in the 1970s and 1980s, which did not use the then most recent seismic data nor have access to data from the U.S. wells. Up to the implementation of the moratorium, no prospects were identified or mapped by industry and government in water depths greater than 200 m, the-then economic and technological limitations to drilling and production. Therefore, deep water turbidite plays, the Abenaki reef margin, and structures containing ancient shallow water sediments now on the deep water slope, were not considered, though today are targets in the Scotian Basin and elsewhere globally (i.e. up to 3000 m water depth). Current technology and new petroleum plays and play concepts, however, broadens the area of petroleum potential and exploration in the Georges Bank region. Since implementation of the moratorium, industry has not been permitted to collect any new seismic data and related geoscience information. Barring new information, government agencies have not undertaken a modern and comprehensive petroleum resource assessment of Georges Bank.

3.2 SEISMIC NOISE

Sound in the ocean is generated by a variety of natural sources (e.g. wind, waves, and the vocalization of marine life) and human activity (e.g. navigation, dredging, pile driving, fishing gear operation, seismic surveys, and military sonar operations). Oceanographic characteristics such as bottom geomorphology, water depth, temperature, salinity, and density can influence the transmission of sound as it travels through the water. For example, sound levels tend to quickly attenuate with range in shallow waters. In deeper waters, sound typically propagates with lower attenuation and, especially so, where acoustic channels exist to conduct and vertically constrain sound energy from lossy interactions with the water surface and bottom (DFO, 2007c).

Seismic surveys use sound waves to gather information about geological structures lying beneath the surface of the Earth, in order to understand the composition, structure, and deformation history of the Earth's crust and/or to locate rock formations that could potentially contain hydrocarbons (Figure 3-1). The general procedure is for a vessel to transit along straight line transects while towing an array of sound sources (air guns) at a predetermined depth. The sound sources emit a signal capable of penetrating deep into the seabed, with the sound signal reflecting back from the different geological interfaces. The return signals are registered by hydrophones encased in a 'seismic streamer' that is a buoyant cable several kilometres in length and trails behind the seismic vessel. The data that is recovered is processed into an acoustic image of the underlying geological strata from which traps or probable concentration areas of petroleum resources can be identified.

In use since the 1960s, air guns have become the most widely used sound source for seismic surveys. They replaced the use of explosives that entailed both safety and acute environmental concerns. Airguns release a specified volume of air under high pressure, which creates a sound pressure wave from the expansion and contraction of the released air bubble. To yield high intensities, multiple airguns are fired with precise timing to produce a coherent pulse of sound. As described by Greene and Moore (1995), Richardson et al. (1995), and Hildebrand (2005), airguns used by the oil industry are typically arranged in arrays of twelve to forty-eight individual guns of various sizes distributed over a horizontal area approximately 20 m inline by 20 m cross-line; where inline refers to the direction in which the ship is sailing and cross-line is perpendicular to it. In an array, the guns are in 3 to 6 sub-arrays called strings with each string being made up of 6 to 8 guns. The array is towed approximately 200 m behind a vessel, as measured from the vessel's navigation point, and suspended by floats at a depth of 3-10 m. The guns operate at pressures of approximately 2000 pounds per square inch (psi), or 137 bar, and fire every 10-15 seconds. To a rough first approximation, the pressure output of an airgun array is proportional to its operating pressure, the number of airguns, and, for a fixed number of guns, the cube root of the total gun volume (Caldwell and Dragoset, 2000).

In order to predict airgun-array sound levels at long range, array source levels are usually expressed as the decibel (dB) pressure level relative to 1 micro Pascal (μPa) observed for an equivalent point acoustic source observed at a 1 m reference range. Typical zero-to-peak source levels for exploration seismic arrays in their primary radiation direction are 245-260 dB relative to 1 μPa at 1 m. While the source level can be used to accurately predict pressures in the 'far field' of the array, an actual seismic array constitutes distributed rather than point source with the result that 'near field' maximum zero-to-peak pressure levels are normally limited to about 190-250 dB relative to 1 μPa. The far-field pressure from an airgun array is focused vertically, with the most important frequency components being enhanced up to 6 dB in the vertical direction by in-phase reflections from the water surface and with broadband vertical sound levels exceeding those radiated in the horizontal direction by typically 8-13 dB depending in part on how these levels are defined and measured (Davis et al., 1998). The peak pressure levels for industry arrays are in the 5-300 hertz (Hz) range. As outlined by the International Association of Geophysical Contractors, industry has adopted a phased sequential approach to the use of seismic noise in their operations: 1) 2D and 3D exploratory operations; 2) more localized geohazard and vertical seismic profiles; and last 3) less frequent 4D operations aimed at determining reservoir changes over time during the production phase (IAGC, 2002).

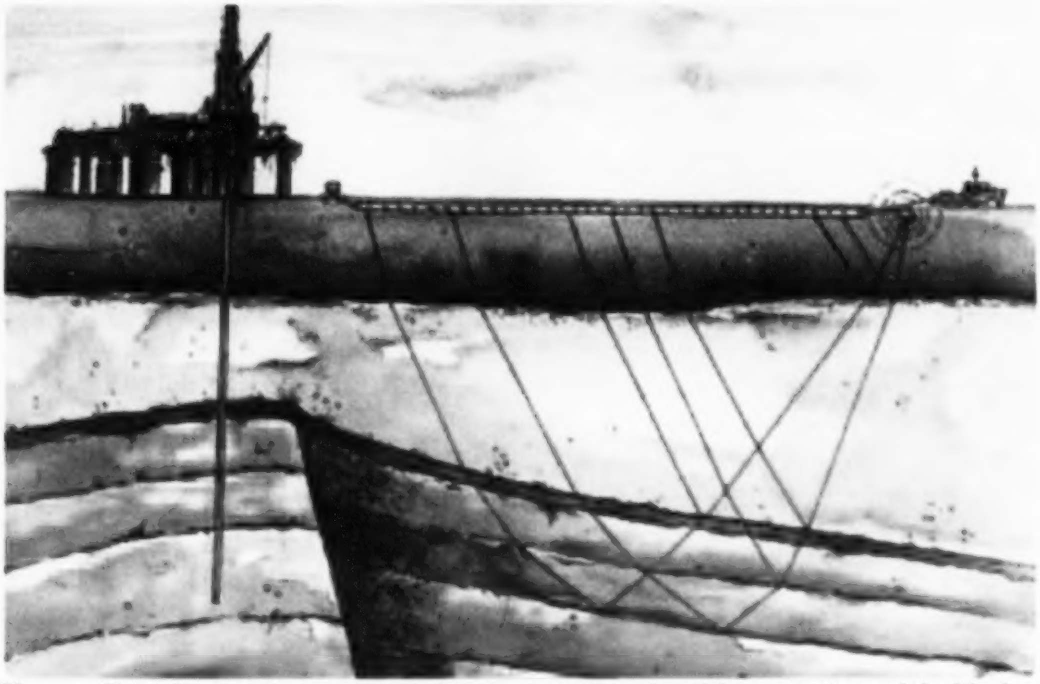


Figure 3-1. A signal source and one or several cables are towed behind a seismic vessel. The sound signals from the air gun are sent into the seabed and reflected by the various stratigraphic layers before being registered by the hydrophones inside the cables (OLF, 2004).

A modern 3D seismic-reflection survey consists of a series of parallel passes through an area by a vessel towing an airgun array along with six to ten seismic receiving streamers (hydrophone arrays) at a speed of approximately 5 knots (2.5 m s^{-1}). The duration of seismic programs typically range from 14-30 days. In contrast to the 2D methods that use a single air gun array and one seismic cable for mapping widely spaced 2D slices of the sea bottom, 3D methods require the operating vessel to transit along more closely-spaced parallel lines (i.e. 100-500 m apart). They also include multiple hydrophone cables and, in certain instances, several airgun arrays that can produce data sets that can be processed with advanced software to reveal the 3D geometry of the subsurface at high resolution (i.e. fine scale). The offshore petroleum exploration industry has routinely used marine 3D seismic reflection methods for over 30 years to map geological structures down to several kilometres depth and up to resolutions of tens of metres. The aim is to detect hydrocarbon reserves. As noted above, a recent innovation is the use of repeated seismic reflection surveys for 'time lapse' monitoring of producing oil fields, known as four-dimensional (4D) surveys, in which the depletion of producing reservoirs can be directly observed.

The seismic emissions from air guns during survey operations are categorized as pulsed noise, as the sound source is discharged on the order of every ten seconds (at intervals of about 25 m along track). Seismic survey-related noise can also appear in more continuous forms, such as that generated by engines, propellers, motors and pumps, etc. The extreme length of the seismic streamer, which contains receivers, cabling, and oil to maintain its neutral buoyancy, reduces the seismic vessel's maneuverability and, therefore, the vessel requires a large turning radius to transfer its operations from one line to the next. Apart from potential impediments to navigation and small oil leaks, however, the seismic streamer itself is not considered of environmental concern (Figure 3-2).

Concerns have been raised about the potential impacts of seismic noise on marine species. In response to these concerns, DFO has produced a number of publications that summarize the results of recent noise impact studies, as well as provide an overview of scientific knowledge and recommendations for future research on the impacts of seismic sound on fish, invertebrates, marine turtles, and marine mammals (DFO, 2003a; DFO, 2004c; Moriyasu et al., 2004; Payne, 2004; Courtenay et al., 2009). The following sections on the interactions of seismic noise with marine species do not attempt to duplicate these reports, rather they attempt to identify key issues and expand upon new research conducted since their publication.

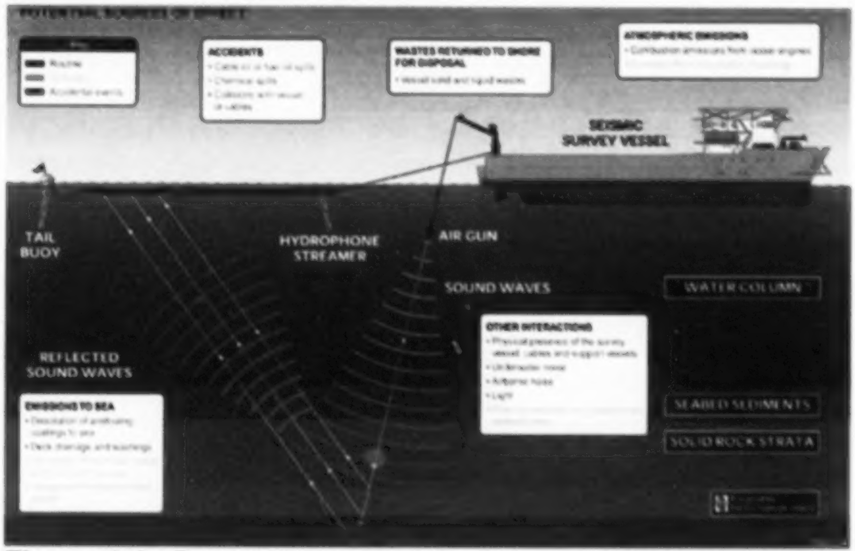

ACCIDENTS
WASTES RETURNED TO SHORE FOR DISPOSAL
ATMOSPHERIC EMISSIONS
SEISMIC SURVEY VESSEL
TAIL BUOY
HYDROPHONE STREAMER
AIR GUN
SOUND WAVES
WATER COLUMN
OTHER INTERACTIONS
REFLECTED SOUND WAVES
EMISSIONS TO SEA
SEABED SEDIMENTS
SOLID ROCK STRATA

Figure 3-2. Potential sources of environmental effects from a seismic survey (Hurley, 2009).

3.2.1 Impacts of Marine Environment

3.2.1.1 Impacts on Fish and Invertebrates

Numerous studies have shown that organisms can be killed or damaged when exposed to sound pulses that have a rapid rise time that exceed 220-230 dB (due to rapidly increasing sound pressure) (reviews by: Turnpenny and Nedwed, 1994; OLF, 2004). Sound pulses from air guns typically have relatively slow rise times, which enable organisms to tolerate higher peak pressure levels than those generated by explosive charges underwater. Sound pulses with a peak pressure of more than 230 db only occur in the immediate vicinity of air guns, within a radius of a few metres.

Studies conducted in Norway (e.g. reviewed by Dalen et al., 2007) and Canada (e.g. Payne, 2004) have conclusively shown that very high levels of seismic noise can adversely impact the eggs and larvae of fish and shellfish. Within the near-field, the sound source generates a compression and decompression wave in the water that impacts certain life stages. Due to three-dimensional dispersion of spreading, the energy decreases quickly with distance from the source. From experiments reported to date, results show that exposure to sound may impact the development of eggs and cause developmental abnormalities in a small proportion of exposed eggs and/or larvae. Results have also shown that injuries and increased mortality from air gun shooting generally occur at distances less than 5 m from the air gun, with the most frequent and serious injuries occurring at distances of less than 1.5 m. Fish in the early stages of life are most vulnerable. In addition, there is also a question of whether chronic low level sound exposures in a given area over a period of 2-3 weeks or more might adversely affect any of a variety of important physiological functions in fish or shellfish.

The potential for population-level impacts as a result of damage to eggs and larvae in the near-field is less clear. Boudreau et al. (1999) postulated that seismic operations in the vicinity of a frontal system or convergent zone that would at certain times of the year have higher densities of eggs and larvae, such as those known to occur on Georges Bank, may cause a significant reduction in year-class size. Following detailed analysis of data, Dalen et al. (1996) concluded that there would be such a small quantity of eggs and fry present within the danger zone that damage caused by air guns would have no consequences for the fish stocks. Thus, according to Dalen et al. (1996), seismic induced mortality is not expected to have a significant negative impact on recruitment. Field studies have not been conducted to test this hypothesis.

There is increasing evidence that significant, but less acute, damage may affect fish from considerably lower sound levels. Damage to the sensory epithelia (i.e. hearing organs) of adult fish has been reported by McCauley et al. (2003), who caged pink snapper and subjected them to the repetitive firing of air guns. Signs of damage to the sensor hair cells in the inner ear were observed as early as 18 hours after exposure to the air gun noise. The damage to the caged animals was severe, with no evidence of repair or replacement of damaged cells even up to 58 days post-exposure. Peak acoustic levels were of the order of 180-190 dB root mean square (RMS) corresponding to predicted acoustic levels less than 500 m from a large exploration seismic array. The fish were caged and unable to swim away from the seismic source as it approached. It is expected that in the wild fish would swim away from the seismic source, which is an anticipated natural avoidance response (at least for some species) that would generally reduce exposure levels. The authors have also observed fish exhibiting disorientation and abnormal swimming behaviour, which might indicate vestibular damage.

There have been no documented cases of large-scale fish mortality due to exposure to seismic sound under field operating conditions. Seismic noise, however, has the potential to have at least short term impacts on certain fish species such as provoking a startle response, changes in swimming patterns (potentially including alterations in swimming speed and directional orientation), and changes in vertical distribution (Worcester, 2006). Such effects have been observed up to a radius of more than 30 km from the sound source (Engås et al., 1996). If fish on route to spawning grounds are exposed to this type of noise or, if they are exposed to seismic noise during actual spawning, the effects may impact their spawning success. For instance, exposed fish may expend more energy on the spawning journey than fish that are not exposed to seismic noise, while spawning itself may be deferred in time or displaced in space (Worcester, 2006).

There have been a number of studies reporting the potential impacts of seismic shooting on the behaviour of fish and catch rates (e.g. Dalen and Raknes, 1985; Pearson et al., 1992; Skalski et al., 1992; Løkkeborg and Soldal, 1993). To collect quantitative data on the spatial and temporal extent of the effects of seismic operations, Engås et al. (1996) conducted a controlled, full-scale experiment to determine if seismic exploration affected abundance or catch rates of cod (*Gadus morhua*) and haddock (*Melanogrammus aeglefinus*). This study, which involved both acoustic mapping and fishing trials with trawls and longlines, was conducted in the central Barents Sea seven days prior, five days during, and five days after seismic shooting with air guns. Results showed that seismic shooting affected fish distribution, local abundance, and catch rates in the entire investigation area of 40-by-40 nautical miles.

Trawl catches of cod and haddock, and longline catches of haddock, declined on average of approximately 50% by mass following the commencement of seismic shooting. This observation was in agreement with the acoustic abundance estimates. The average longline catches of cod decreased by 21% by mass following the commencement of seismic shooting. Reductions in catch rates were observed up to 18 nautical miles from the seismic shooting area (which was 3 by 10 nautical miles in size). The most pronounced reduction in catch rates, however, occurred in the seismic shooting area, where trawl catches of both cod and haddock, and longline catches of haddock, decreased on average by approximately 70% by mass. The longline catches of cod decreased on average approximately 45% by mass. Interestingly, a greater reduction in catch rates by mass was found for larger fish (i.e. greater than 60 cm in length) than for smaller fish (both in trawl catches and acoustic estimates). Last, Engås et al. (1996) found that the abundance and catch rates did not return to preshooting levels during the five day post-seismic shooting period.

Hassel et al. (2004) studied the influence of seismic shooting on a sandeel (*Ammodytes marinus)* in the North Sea. Remote camera systems were used to observe caged animals exposed to full-scale seismic shooting for approximately 2.5 days. Comparisons were made to animals in a control area about 35 km southeast of the seismic shooting area. The results indicated that the seismic shooting had an effect on the behaviour of the sandeel. Changes in the distribution and abundance of the sandeel during daytime in the experimental region could not be detected by acoustic surveys. Repeated grab surveys were also conducted with a van Veen grab at night at predetermined locations during the experimental period, both prior to and after seismic shooting. No differences in lethality were observed in both the caged animals and grab sampled animals. However, analyses of landing data from the Norwegian sandeel trawlers fishing within the area of seismic shooting showed a drop in the sandeel landings for a short period during and after the ensonification period.

As described in an overview by Dalen et al. (2007), scare effects on fish can result in catch reductions that vary by species and by the fishing gear being used. For example, a Norwegian survey demonstrated reduced trawl catches of cod out to approximately 33 km from a seismic sound source, while another study demonstrated reduced line catches out to approximately 8 km from the sound source. Results of a study in Australia demonstrated that scare effects of fish out to distances of 1-2 km from a seismic vessel. The Australian data could not be used to determine if the frightened fish returned to the area that they abandoned or re-appeared in some other manner (e.g. fish migrated off the bottom into echo sounder range).

Løkkeborg et al. (2010) recently completed a study for the Norwegian Petroleum Directorate to evaluate the degree to which fish occupying a designated study area off Vesterålen were affected by seismic shooting activity. Seismic data were collected in an area bounded by 8 by 46 nautical miles during a period of 38 days (June 29 to August 6, 2009), as the vessel *Geo Pacific* conducted a standard 3D seismic data acquisition survey. The seismic survey site overlapped with an area of traditional fishing grounds for Greenland halibut (*Reinhardtius hippoglossoides*), redfish (*Sebastes marinus*), pollock (*Pollachius virens),* and haddock (*Melanogrammus aeglefinus*). The survey was scheduled during a period when few gadoids would be expected in the area and, thus, fishing activity was limited. During the seismic survey, two gillnet boats fished for Greenland halibut, pollock and redfish, while two longline boats fished for Greenland halibut and haddock. Fishing operations began 12 days prior to the seismic survey and continued up to 25 days following completion of the seismic program. The research vessel *Håkon Mosby* and chartered fishing vessel *Eros* carried out an acoustic survey of the distributions of fish and plankton in the area, in order to determine whether changes in abundance could be observed before, during, and after the seismic survey. Sound measurements were also taken at a range of depths and distances from the seismic air-guns.

Results of the Løkkeborg et al. (2010) study revealed that the sound of the air-guns affected the fisheries in the study area off Vesterålen in a number of ways. Specifically, fish catches of individual species increased and decreased by fishing gear type. For example, gillnet catches of Greenland halibut and redfish increased during seismic shooting and remained high following the survey compared to observations made prior to the survey. In contrast, long-line catches of Greenland halibut decreased during the seismic survey, but subsequently increased during the 25-day period following the survey. Results for pollock demonstrated a decrease in gillnet catches both during and after the seismic survey, although the differences were not statistically significant.

The decline in gillnet catches of pollock was in agreement with estimates from the acoustic survey. In general, the acoustic survey demonstrated a decrease in quantity of pollock in the vicinity of the seismic survey and in the adjacent area close to land, during seismic shooting, although the difference was only statistically significant in the shoreward area where the pollock were most abundant. This finding was interpreted as an indication that pollock left the area in response to the seismic survey. Unfortunately, the high degree of variance in the data made it difficult to determine how long the reduction in pollock lasted following the survey. Last, by-catch of ling (*Ophiodon elongatus*) in redfish and pollock nets increased immediately after the start of seismic shooting. After a few days of seismic activity, ling catches subsequently decreased and, during the observation period following the seismic survey, had returned to similar or slightly lower levels than those observed prior to the seismic survey.

There were large day-to-day variations in long-line catches of haddock, although statistically-significant differences in haddock catch rates observed before and during the seismic survey were not observed. The area in which the haddock fishery took place was less affected by the sound of the air-guns than the fishing grounds for other species, since there was no direct overlap between this area and the seismic vessel transects (Løkkeborg et al., 2010). It was only during the final three days of the seismic survey that the survey vessel was less than one nautical mile from the haddock longlines for a short period each day. Nevertheless, there was a decreasing trend in haddock catches towards the end of the period of seismic activity, with a positive correlation between catch rates and distance from the seismic vessel being observed (Løkkeborg et al., 2010). In short, the study demonstrated that catches decreased when the distance to the survey vessel decreased, suggesting that haddock catch rates were affected by the sound of the airguns.

Acoustic survey results on the distribution of demersal fishes in the seismic survey area largely confirm the results of the fishing experiments. During seismic shooting, lower abundances of pollock were measured in the area between the seismic survey area and land, although there was also a tendency for a decrease in pollock abundance in the seismic survey area. No changes in abundance or distribution of other demersal fishes could be ascribed to the seismic campaign, although concentrations of juvenile herring (*Clupea harengus*) were observed to migrate out of the seismic survey area during the experiment. This behaviour, however, was also observed to occur in the control area and was interpreted as the natural feeding migration for juvenile herring.

Plankton observations demonstrated uniform concentrations throughout the study area, with no changes in plankton concentration or distribution being observed throughout the study period. In addition, the analysis of fish stomach contents indicated no change in food uptake as a result of the seismic survey. Decreases in the stomach contents of pollock and haddock of gillnet and longline fishing experiments during the seismic survey, however, were observed, although no decrease in the stomach contents of trawl-caught fish was observed. A decrease in the amount of herring found in the stomach contents of pollock captured by gillnet corresponded to the acoustically-measured decrease in abundance of herring in the experimental area. This was attributed to the natural migration of herring out of the study area.

Results of the Løkkeborg et al. (2010) study indicate that all the fish species studied reacted to sound associated with the seismic air-guns, as catch rates of the various species either increased or decreased during seismic shooting. Sound measurements demonstrated that all of the fish studied were exposed to sound levels above their hearing threshold and in a range where obvious changes in swimming activity can be expected. The findings are supported by fish raising their level of swimming activity, thus, causing Greenland halibut, redfish, and ling more vulnerable to be taken by gillnets, whereas pollock likely migrated out of the study area. The increase in swimming activity of fish may be a symptom of a stress reaction that could lead to reduced longline catch efficiency, either as a result of reduced feeding motivation or because the fish migrated out of the study area. Due to study limitations, it was not possible to determine the maximum distances within which the fish reacted to the sound of the air-guns.

In the Bass Strait of Australia, scallop dredge fishermen expressed concern that seismic testing may increase the mortality of larval scallops, weaken the adductor muscle, and/or kill adult scallops. In response, Esso Australia commissioned a study in 2001 to investigate the impacts of seismic testing. The effects of seismic testing on adult scallops were measured by comparing the mortality and adductor muscle strength of scallops deployed in an area subject to seismic testing with those in a control area distal from the seismic survey area. The effects of seismic testing on plankton, including larval scallops, were measured by comparing plankton communities immediately behind the seismic vessel with those sampled before and 2 km away from the seismic testing. The study found that the mortality rate and adductor muscle strength of scallops suspended 19 m below the surface in the path of the airgun array were not significantly different than those of scallops placed at the control site 20 km away (Exxon Norge AS, 2001).

In the Bay of Biscay, Guerra et al. (2004) noted that two incidents of giant squid (*Architeuthis dux*) strandings appeared to be linked spatially and temporally to geophysical prospecting operations involving air-gun arrays. Evidence of acute tissue damage was observed in the stranded and surface-floating giant squids. The incidence of these cases during periods of geological and geophysical studies using acoustic air guns generating low frequency (<100 Hz), high intensity (200 dB) sounds suggested that acoustic factors caused or contributed to organ and tissue lesions that likely caused the squid mortalities.

In Atlantic Canada, there is evidence from recent studies suggesting that invertebrates are sensitive to acoustic sound (Christian et al., 2003; Payne et al., 2007). In comparison to controls, Christian et al. (2003), as part of a larger preliminary study in which little or no effects were observed, reported delayed embryonic development in fertilized snow crab eggs exposed to 200 seismic shots at 180 dB RMS. To follow up on the preliminary study, a major field study was conducted by DFO, in conjunction with a seismic survey conducted by Corridor Resources off the west coast of Cape Breton, Nova Scotia. A caging study examined short (i.e. 12 days) and medium (i.e. 5 months) term differences in the morphology and physiology of egg-bearing female snow crab at test and control sites. Three definitive conclusions were made following peer-review of the work (DFO, 2004c): 1) the seismic survey did not cause any acute or mid-term mortality of the crab nor was there any evidence of changes to feeding in the laboratory; 2) survival of embryos being carried by female crabs, as well as locomotion of the resulting larvae after hatch, were unaffected by the seismic survey; and 3) in the short term, gills, antennules, and statocysts (i.e. balance organs) were soiled in the test group, but they were found to be completely cleaned of sediment when sampled five months later.

Other significantly different observations in the DFO (2004c) study between the test and control sites, such as bruising of the hepatopancreas and ovaries (including dilated oocytes with detached chorion), delay of embryo hatch and smaller size of larvae, and turnover time of crabs in the test site, could not be explained due to confounding factors such as temperature differences between sites. This was subsequently addressed in a series of follow-up studies (e.g. Courtenay et al., 2009), which highlighted the need for alterations in the experimental design of field trials. For example, the slower rate of embryo development between the test and control groups could be attributed to temperature differences as well as exposure to seismic sound. Following statistical analysis of the data, Lee and Wright (2009) concluded that no significant correlations could be made with seismic exposure and observed histopathologies in the crab hepatopancreas and gonad tissues. Furthermore, a high degree of correlation was observed between the degree of histological abnormalities and caging time. As a result, it was concluded that chronic damage/recovery was difficult to assess due to confounding events associated with the crowded cage conditions and limited food supply.

Pearson et al. (1992) investigated the effects of airgun discharges on survival and growth of Dungeness crab (*Cancer magister*) larvae. An array of seven airguns discharging as close as 1 m away from the larvae did not affect crab larval survival. Upon completion of a subsequent independent follow-up study on snow crab, Payne et al. (2008b) stated:

> Evidence supporting a hypothesis that the various effects observed were due to normal variability (and not due to seismic) has also recently been obtained from an Environmental Studies Research Fund (ESRF)-supported study in Newfoundland (DFO, NL Region, unpublished). Female crab were exposed to higher sound levels than those measured at the test site in the Cape Breton study and maintained in the lab for several months. No difference was observed with respect to mortality, leg loss, egg loss or hepatopancreas, and ovary histopathology. The results support the earlier preliminary study on snow crab carried out by Christian et al. (2003).

Lobster (*Homarus americanus*) is one of the most commercially-important species in Atlantic Canada. Payne et al. (2007) have conducted pilot studies in the laboratory and field to investigate the potential effects of seismic sound on lobster health. A number of biological endpoints, including sub-lethal responses, were assessed in animals exposed to 'low level' (202 dB peak-to-peak) and 'high level' (to 227 dB peak-to-peak) sound. The endpoints included: lobster survival; food consumption; turnover rate; serum protein; serum enzymes; and serum calcium. Exposure of lobster to very high and low sound levels had no effect on delayed mortality or damage to mechano-sensory systems associated with animal equilibrium and posture, as assessed by turnover rates (Payne et al., 2007). There was also no evidence for loss of legs or other appendages. Sub-lethal effects, however, were observed with respect to feeding and serum biochemistry, with effects sometimes being observed weeks to months after exposure. A histochemical change was also noted in the hepatopancreas of animals exposed 4 months previous, which may be linked to organ 'stress'. These initial studies were meant to be exploratory in nature and caution is warranted about over interpretation. They do however point to the need for more comprehensive studies regarding the potential for seismic surveys to affect lobster. Studies on moulting and effects on egg development and animal behavior are recommended (Payne et al., 2007).

Exposure to seismic sound is considered unlikely to result in direct invertebrate mortality, but the question of the potential for delayed effects of an adverse nature requires further investigation. Seismic noise has the potential to cause short term impacts on some invertebrate species, including startle responses and changes in swimming/movement patterns (such as changes in swimming/movement speed and directional orientation). Moriyasu et al. (2004) felt that the ecological significance of these effects would be low, except if effects of exposure to seismic sounds were to influence reproduction or growth/moulting activities or lead to a dispersion of spawning aggregations or deflection from migration paths. Parry and Gason (2006) studied catch rates of rock lobster (*Panulirus interruptus*) following seismic surveys and reported that there was no evidence of a relationship between seismic surveys and long-term changes in catch rates. They indicated, however, that seismic-induced mortality would have to be major (i.e. in the 50% range) before it could be resolved from natural and fishing mortality. Parry and Gason (2006) suggest that perhaps because most invertebrates do not contain sound sensitive organs, such as air bladders like those found in fish (Keevin and Hempen, 1997), invertebrates may be less vulnerable to proximal loud sounds/explosions.

3.2.1.2 Impacts on Marine Mammals

Although seismic airgun arrays are designed to direct the majority of emitted energy downward through the seafloor, their sound emission horizontally is also significant (NRC, 2003a). Six autonomous hydrophones moored near the Mid-Atlantic Ridge (from latitude 15-35°N and longitude 33-50°W) to record spectrograms of whale vocalizations clearly picked up the sound of seismic airgun activity from locations over 3000 km from the array (Nieukirk et al., 2004). The broadband frequency range and repeated firing of these guns make them a major contributor to the low-frequency sound field in the North Atlantic. The effects of seismic noise on whales are not fully known. Possible effects include masking of conspecific sounds, increased stress levels, changing vocalizations, abandonment of important habitat, ear damage, and alteration of reproductive or immune responses (Richardson et al., 1995; Hildebrand, 2005; Weilgart, 2007).

Clark and Gagnon (2006) noted that Mysticete whales produce a wide variety of communication sounds in the very low frequency range (<100 Hz), and possess auditory systems well adapted for hearing low frequency sounds (<1000 Hz). The low-frequency energy associated with seismic operations may cover spatial areas of ecological importance over time periods of biological significance. A comprehensive assessment of the potential impacts linked to such chronic exposures to individuals and populations, either alone or in synergistic combination with other stressors, was recommended to fully document proximate and cumulative exposure levels and the types and scales of responses (e.g. behavioral, endocrinological, physiological, neurophysiological) within the proper ecological context. Di Iorio and Clark (2009) noted that blue whales

(*Balaenoptera musculus*) in the St. Lawrence River Estuary changed their vocal behaviour during a seismic survey that deployed a low-medium power technology (sparker with source level of 193 dB relative to 1 µPa peak to peak). The whales were found to consistently call more on seismic exploration days than on non-exploration days, as well as during periods on a seismic survey day when the sparker was operating. This is in line with the prediction from information theory, which indicates an increase in call production to compensate for the masking of information by noise.

The results of a comprehensive study by Stone and Tasker (2006) on the effects of a seismic survey in the United Kingdom on cetaceans demonstrate that cetaceans can be disturbed by seismic exploration. Sighting rates, distance from the airguns, and orientation were compared for periods when airguns were active and when they were silent, both for surveys with airgun arrays of large volume and surveys with smaller volume arrays. Small odontocetes demonstrated the strongest lateral spatial avoidance (extending at least as far as the limit of visual observation) in response to active airguns, while mysticetes and killer whales demonstrated more localized spatial avoidance. Long-finned pilot whales demonstrated only a change in orientation and sperm whales demonstrated no statistically significant effects. Responses to active airguns were greater during those seismic surveys with large volume airgun arrays than those with smaller volumes of airguns.

Stone and Tasker (2006) suggested that the different taxonomic groups of cetaceans may adopt different strategies for responding to acoustic disturbance from seismic surveys; some small odontocetes move out of the immediate area and the slower moving mysticetes orient away from the vessel and increase their distance from the source, but do not move away from the area completely. The study concentrated on examining short-term effects of airgun activity on the occurrence and orientation of cetaceans. Long-term effects, effects on vocalizations, behaviour and physiology, consequences of auditory masking, and the potential for damage to hearing were not considered in the experimental design. The lack of an observed response in some species does not, therefore, imply that the use of seismic airguns has no effect on those species. Furthermore, although the responses that were observed were short-term effects, it is not known whether these may have been biologically-significant effects that persisted beyond the time of disturbance, responses that affected the ability of animals to engage in essential activities (e.g. breeding, feeding, caring for young, migrating, etc.), or effects that had consequences at the population level. Difficulty in determining the biological significance of observed effects is recognized (NRC, 2003a; 2005).

There is evidence that seismic noise may inflict physical impacts to marine mammals. For example, there have been observations, under experimental conditions, of sub-lethal, temporary elevations in hearing thresholds (temporary threshold shift or TTS) in captive marine mammals exposed to pulsed sounds. A panel-based consensus of the best science-based criteria for marine-mammal noise exposure considering, for instance, the varying frequency domain auditory sensitivity of differing categories of marine mammals has been published by Southall et al. (2007) and may well serve as a starting point for refined species-specific exposure limits in the future. There are a few indications that marine mammals suffer injury to internal organs as a consequence of anthropogenic sound. A database was established from the results of studies on three mass strandings of beaked whales that occurred during the same time period as naval exercises involving sonar. There was strong evidence that there were bubble-induced lesions and fat embolisms in vital organs consistent with 'the bends'. The authors concluded that observed damage was unlikely to have been caused directly by acoustic exposure but rather from altered diving patterns induced by the exposures. There are no such observations for seismic surveys (Dalen et al., 2007).

Exposure to seismic sound can result in displacement and/or migratory diversion in some marine mammals, but this effect is species, individual, and contextually related. The ecological significance of such effects is unknown, but there are conditions under which the worst case scenarios could be high, such as: feeding marine mammals being displaced from areas where there are no alternates; marine mammals being displaced from resting areas where there are no alternates; marine mammals being displaced from breeding or nursery areas; or migrating animals being diverted from routes for which alternate routes either do not exist or would incur substantially greater costs to traverse. In addition, exposure to seismic sound can result in changes in dive and respiratory patterns in some marine mammals, but this effect is expected to vary with species, individual, and context. Furthermore, when dealing with species-at-risk (*Species at Risk Act*-listed species), detrimental effects suffered by one individual can translate into detrimental effects on the population.

There is evidence that exposure specifically to seismic sounds has sometimes caused changes in vocalization patterns in marine mammals. It has not been possible, however, to measure the functional consequences of these changes (such as loss of contact between individuals or reduced ability to coordinate social behaviours), if any, nor the percent of time with which they would occur (Lawson and McQuinn, 2004). A field study was conducted in the Gully and outer Scotian Shelf of Atlantic Canada in 2003 to determine the impact of a seismic exploration program on marine mammals, including the endangered Northern Bottlenose Whale as listed pursuant to the *Species at Risk Act* (Lee et al., 2005a). This program included studies of seismic sound levels, as well as behaviour, vocalizations, and distributions of marine mammals both in close proximity to the seismic vessels and in adjacent areas including the Gully submarine canyon and shelf edge of the Scotian Shelf during an exploratory 2-D and 3-D seismic program. Marine mammals were observed both visually and acoustically. Marine mammals appeared to have avoided very close ranges (<100 m) from the seismic array during seismic acquisition, but the overall number of marine mammals in the observable radius (1-2 km) did not change significantly when the seismic source was 'on' versus 'off'. Marine mammals were observed in larger groups and appeared to have become less vocal when the seismic source was active (Potter et al., 2005).

Whale vocalizations were recorded at all stations. An analysis of results indicated that they did not abandon the Gully area while 3D seismic exploration was carried out in the survey area, at ranges larger than 30 km (Simard et al, 2005). Changes in the composition, distribution, and abundance of marine mammal species between the spring and summer surveys were most likely attributed to seasonal variation rather than the effect of seismic activity (Gosselin and Lawson, 2005). The validity of any assessment regarding potentially-harmful impacts of seismic sound on marine mammals will depend crucially on the accuracy and applicability of acoustic propagation models and the data used in the process. During the study, measured sound levels were significantly higher than the model predictions at several stations (Cochrane, 2005; McQuinn and Carrier, 2005). The results demonstrated the importance of using sophisticated models, accurate model parameterizations, including proper representations of the source at frequencies above 200 Hz, the necessity of field validation, and the ongoing need for improved instrumentation for monitoring both seismic sounds and the vocalization of marine mammals (Vagle et al., 2005).

Det Norske Veritas conducted a review of reported incidents involving seismic noise and marine mammals (Dalen et al., 2007). They concluded that there has been no documented sea mammal mortality as a consequence of seismic surveys, as studies of individual incidents in which whales have stranded and seismic activity has occurred in the same area during the same time have been unable to document a direct cause and effect link. Nor are there any documented injuries to marine mammals as a result of seismic surveys. The effects observed were typical changes in behavior, such as whales leaving areas where there was seismic activity. While it was confirmed that seismic surveys may have certain negative consequences for marine life in the nearby area, their review concluded that there are no results that indicated serious and long-lasting harm to populations of fish and marine mammals (Dalen et al., 2007).

Many marine mammals use the Georges Bank area on their migratory routes and as a feeding ground because of the high densities of prey available. Although there are no documented cases of marine mammal mortality resulting from exposure to oil and gas exploration seismic surveys, immediate behavioural reactions as a result of exposure to seismic sound have been widely documented for several classes of marine organisms, and especially for marine mammals, in the latter case precipitating behaviours resulting in the animals temporarily avoiding the immediate area of the sound source or reducing their own vocalizations. Despite the research undertaken to date, additional research may be needed to determine the ecological significance of effects attributed to the exposure to seismic sound linked to:

- changes in marine mammal social behaviour;
- reduced communication and echo-location efficiency in marine mammals;
- hampering of acoustic detection of prey by marine mammals;
- increase in the vulnerability of marine mammals to predators;
- hampering of parental care or bonding in marine mammals;
- reduction in the ability of marine mammals to avoid anthropogenic threats;
- chronic effects on marine mammals; or
- indirect effects on marine mammals.

3.2.1.3 Impacts on Sea Turtles

While there has been an increased interest in sea turtles because of the endangered or threatened status of some species, relatively little is known about the sensitivity of these species to sound, including seismic noise. Studies do indicate that sea turtles are able to detect and respond to sound frequencies in the range generated during seismic surveys. Scientific studies that have been conducted to date have provided evidence of short-term physical response (e.g. change in hearing sensitivity), physiological response (e.g. increased levels of creatine phosphokinase, glucose, and white blood cell counts), and behavioural responses (e.g. increased swimming speed and activity) of caged turtles within 500 m of an airgun source (O'Hara and Wilcox, 1990; Moein et al., 1994; McCauley et al., 2000).

A few studies have included observations of sea turtles and sea turtle behaviour in the vicinity of seismic surveys. For example, Eckert et al. (1998) attempted a behavioural study of free ranging leatherback turtles in the proximity of a seismic survey, however, limited reporting of experimental detail make results difficult to interpret. Eckert et al. (1998) also attempted to estimate possible broader scale response of sea turtles to seismic noise based on information available from non-seismic related studies. Using the peak pressure level required to obtain TTS in a desert tortoise (~120 dB above best hearing threshold with repeated exposure) and the reported sensitivity of the green turtle in air (65-79 dB re 1 µPa), he predicted that repeated exposure to airgun pulses above 185-199 dB re 1 µPa (conservative estimate) could have long-term effects on hearing. It is not clear that this is a valid approach.

Turtles were observed during seismic operations in Brazil between June 2002 and August 2003 (Moreira-de-Gurjao et al. 2005; Parente et al., 2006). Three species of turtle were identified. Most identified turtles were green sea turtles (*Chelonia mydas*); one loggerhead turtle (*Caretta caretta*) and one olive Ridley turtle (*Lepidochelys olivacea*) were also seen. The turtle sightings rate in quiet periods (0.075 turtles per hour) was higher than that during seismic surveying (0.054 turtles per hour). There did not appear to be significant differences in the behaviour of turtles based on whether or not the airguns were active, though swimming velocity and direction was not recorded. Visual observations for marine turtles have taken place during all 11 Lamont-Doherty Earth Observatory seismic surveys conducted since 2003 (Holst et al. 2006). During use of large seismic sources (11-20 airguns; 3050-8760 cubic inches), the mean closest point of approach for turtles was closer during non-seismic (139 m) than seismic (228 m) periods (P<0.01). Using smaller seismic sources (6 airguns; 75-1350 cubic inches), the mean closest point of approach for turtles was also much closer during non-seismic (120 m) than seismic (285 m) periods (P<0.001). The conclusion of this report was that sea turtles showed localized avoidance during large and small-source surveys.

Observations of turtles were made during two consecutive 3D seismic surveys off northern Angola between August 2004 and May 2005 (Weir, 2007). Two hundred turtle sightings were recorded, including 33 olive Ridley turtles, three leatherback turtles (Dermochelys coriacea), four loggerhead turtles, and 160 unidentified turtles. The turtle sightings rate in quiet periods (0.43 turtles per hour) was double that during seismic surveying (0.20 turtles per hour). There was no significant difference in the median distance of turtle sightings during active airgun use as compared to quiet periods. While a slightly higher proportion of turtles dived during active airgun use (12.5%) as compared to quiet periods (11%), 77% of turtles during seismic testing and 83% during non-seismic testing continued to remain at the surface as the vessel passed. Diving reactions were also observed in response to visual detection of the vessel, the towed surface floats, and the inactive airgun array. Observations were only made of turtles at the sea surface (as opposed to turtles swimming below the sea surface) where received sound levels are expected to be reduced.

Based on studies conducted to date, it is considered unlikely that sea turtles are more sensitive to seismic operations than cetaceans or fish. Therefore, mitigation measures designed to reduce risk or severity of exposure of cetaceans to seismic sounds may be informative concerning potential measures to reduce risk or severity of exposure of sea turtles to seismic sounds. There remains however a lack of research on the acoustic sensitivity of sea turtles and on the importance of the acoustic environment for sea turtles. Differences in functional morphology and hearing capabilities among species and life history stages have not been well documented in the literature (Bartol and Musick, 2003).

Investigations on the potential impacts of seismic noise have only been conducted for a limited number of species. Studies on the potential for noise induced hearing damage in turtles, including structural damage or damage to hair cells, are extremely limited. Studies on the responses of free ranging turtles to seismic noise are also limited and are dominated by environmental effects monitoring observations from seismic vessels. In addition to impacts from seismic noise itself, there is also the potential for impacts to sea turtles as a result of direct interaction with seismic vessels and gear. There have been reports of such interactions during seismic surveys in other parts of the world, particularly with regards to interactions with seismic tail buoys. Some work has been done to develop mitigation measures to minimize these types of interactions (e.g. Ketos Ecology, 2007), including development of turtle exclusion devices or 'turtle guards'. The effectiveness of these measures is not well known.

3.2.2 Mitigation Measures

A number of protocols have been developed in an effort to minimize impacts of seismic surveys, such as: (i) good survey pre-planning to minimize contacts with sensitive marine mammals, endangered marine mammals, as well as to avoid critical fish spawning areas and periods; (ii) "soft starts" of the seismic source to allow mammals (and other sensitive species) the opportunity to vacate the area before commencing the survey; (iii) use of dedicated visual marine mammal trained observers whenever possible with the authority to suspend a survey under pre-defined criteria; and (iv) employment of Passive Acoustic Monitoring (PAM), which is a rapidly developing technology that enables detection of actively vocalizing marine mammals during periods of darkness or reduced visibility (not effective for non-vocalizing animals).

Based on a scientific peer-review of the potential impacts of seismic sound on marine species (DFO, 2004c) and an assessment by technical experts of best available and internationally-recognized techniques to mitigate the effects of seismic sound in the marine environment, a group of federal and provincial experts in marine regulatory policy and practice from DFO, Natural Resources Canada, Indian and Northern Affairs Canada, and the provinces of British Columbia, Newfoundland and Labrador, Nova Scotia, and Quebec, developed a 'Statement of Canadian Practice with respect to the Mitigation of Seismic Sound in the Marine Environment' (hereafter referred to as the 'Statement') (Government of Canada, 2007). The Statement sets out minimum standards that are intended to apply to all seismic activities that use air source arrays in Canada's non-ice covered marine waters. It was intended to complement existing environmental impact assessment processes, including those pursuant to settled land claims, as well as existing regulatory requirements that currently govern marine seismic activities. The Statement is considered a 'living' document and is intended to be reviewed and updated every two years.

In the Statement, mitigation requirements are categorized under the following headings:

- Planning Seismic Surveys;
- Safety Zone and Start-up;
- Shut-down of Air Source Array(s);
- Line Changes and Maintenance Shut-downs;
- Operations in Low Visibility; and
- Additional Mitigative Measures and Modifications.

Variations to the mitigation measures set out in the Statement may be allowed if persons wishing to conduct seismic surveys provide an equivalent or greater level of environmental protection. For example, the Canada-Nova Scotia Offshore Petroleum Board (CNSOPB) requires all seismic operators to carry an independent fisheries observer onboard the seismic vessel to minimize interactions between the seismic vessels and their air gun arrays with fishing vessels and their gear. Dedicated observers are also frequently included in programs to record sightings of marine mammals, sea turtles, and sea birds during seismic programs.

Hurley (2009) noted that companies proposing to conduct seismic surveys in Canadian marine waters may be required to have site-specific environmental mitigation measures to further reduce the risk of harm to marine life. Recent examples of enhanced mitigation measures that have been used in the Nova Scotia offshore include:

- avoidance of special marine areas (e.g. whale sanctuaries and marine protected areas);
- increased size of the safety zone (minimum radius of 500 m) around air gun arrays, in order to increase the area over which seismic mitigation measures such as ramping up and shut-down are applied during operations;
- use of PAM to detect presence of whales below the sea surface or during times of low visibility;
- acoustical modeling and monitoring to verify the seismic noise zone of influence, as predicted in the environmental impact assessment;
- scheduling of survey operations to minimize interactions with fisheries; and
- alteration of vessel speed and orientation of seismic lines to reduce sound energy levels that are required.

Research and development of alternative technologies are also ongoing. These include new sound sources such as marine vibrator systems (e.g. marine vibroseis), electro-mechanical and petrol-driven acoustic projectors that have reduced sound levels (30-65+ dB) above 100 Hz, and novel electromagnetic surveys methodologies based on the measurement of seabed resistivity that may supplement seismic operations under certain conditions. The evaluation of potential biological effects associated with the use of these new technologies is underway. Regardless of the technology, precautionary guidelines to minimize disturbance associated with seismic surveys should continue to be applied until the biological significance of the observed effects can be determined.

3.2.3 Analysis of Risk, Knowledge Gaps, and Research Needs

There have been some studies on the impacts of seismic noise from air guns on marine species as the result of physical (i.e. changes in organisms' physical state including death and injury to organs), physiological (i.e. changes in biological functions or body chemistry) and/or, behavioural alterations (i.e. changes in how organisms behave). Studies to date on invertebrates, fish, marine mammals, and sea turtles suggest that there can be consequences of seismic noise to individuals or groups of animals in the marine environment, but the potential for this to result in population or ecosystem scale impacts continues to be debated. Observed physical impacts appear to be largely confined to within a few metres of the seismic source arrays. Behavioural impacts have been detected tens of kilometres from a seismic source.

The increasing concerns about the effects of underwater manmade noise on marine organisms calls for a standardized system of how to quantify and mitigate noise exposure with relevant and reproducible measures. The RMS measure specified by most regulatory agencies critically relies upon choosing the size of averaging window for the squared pressures. Derivation of this window is not standardized, which can lead to 2-12 dB differences in RMS sound pressure for the same wave forms. This has resulted in inconsistency between scientific studies as there is inadequate information to reproduce and compare measurements. RMS pressure, being closely related to the average energy of a noise pulse, does not prevent exposure to high peak pressures. Recent research has indicated that the sound exposure level (SEL) or the time-integrated sound energy delivered to an animal over the duration of a seismic pulse may be as or more important damage criteria than the traditionally-used RMS and peak pulse pressure levels (Lawson and McQuinn, 2004). Since physical damage and impairment of the auditory system in marine mammals is caused both by high peak pressure and energy flux, Madsen (2005) suggested that safety limits for sound exposure should include both a maximum received energy flux level and maximum received peak-to-peak pressure level. Such a protocol addresses concerns for physical damage due to short, high pressure pulses, as well as the effects of longer, high energy transients with lower peak pressures.

Fisheries and Oceans Canada coordinated a workshop in 2003 to develop a 'Decision Framework for Seismic Survey Referrals', in order to produce an inventory of ecological factors to be considered when dealing with referrals for seismic surveys in Canadian waters (DFO, 2003a). The workshop discussed sources of uncertainty about effects of seismic sounds on the ecological factors and the methods to address these issues in the context of environmental risk assessments. Results were presented the following year at a National Advisory Process meeting on Seismic Impact Evaluation Framework (DFO, 2004c), where it was concluded that seismic sounds in the marine environment are neither completely without consequences nor are they certain to result in serious and irreversible harm to the environment.

The potential for detrimental effects exist and are likely linked to the conditions of the environment (e.g. physical oceanographic factors influencing sound propagation and proximity to and intensity of the sound source arrays) and the organisms being exposed. The documentation of no fish or invertebrate kills during operational surveys, as well as only circumstantial evidence of infrequent strandings of marine mammals and giant squid, however, suggests that seismic surveys with fairly routine mitigation measures in place are unlikely to pose a high risk of mortality to marine organisms. Nevertheless, it was also noted that sublethal or longer-term effects may have occurred and have not been detected by the regulatory monitoring programs that are currently in place. Immediate behavioural reactions (e.g. avoidance of seismic noise and reduced vocalization) have been widely documented in marine organisms, especially marine mammals. The possible long-term effects of these behavioural responses continue to be debated. The effectiveness of mitigation measures, such as a decision not to conduct surveys in specific zones or during critical periods, is influenced by many factors. It was concluded that additional research and development of improved monitoring methodologies are needed to clarify and quantify the unknown risks and uncertain effects of seismic sound on the marine environment.

Payne et al. (2008b) concluded (based on a review of scientific literature published between 2003 and 2008) that the primary concern over the impacts of seismic noise on fish or shellfish is at the stock or sub-stock level, such as in a shallow coastal environment (i.e. bay or inlet). There is also some physiological and histopathological evidence suggesting a potential for seismic noise to have sublethal effects at the individual level. Payne (2004) suggests that a few representative studies on distance-effect relationships for keystone fish and shellfish species, of commercial importance, would greatly aid understanding in this area, with the potential for effects stemming from cumulative energy, as well as peak energy, being considered. This includes under conditions of 3D surveys. The results of these studies would help to identify the need, if any, for air-gun-based sound reference levels for fish and shellfish.

Regarding the potential effects of noise in general, Popper (2003) and Payne et al. (2007), among others, have drawn attention to the need for studies on sub-lethal effects, which are recognized as a major knowledge gap. A recent workshop convened in relation to the North Sea also concluded the following, as stated by Ainslie et al. (2009):

> In the next steps towards an impact assessment, there is insufficient information on physiology and behaviour of the marine fauna of the North Sea. There is also a lack of knowledge on the effects of the various anthropogenic sources of sound on the ecosystem of the North Sea, both individually and cumulatively.

To directly address identified knowledge gaps, the Joint Industry Programme on Sound and Marine Life supported by the International Association of Oil and Gas Producers (OGP) hosted a workshop in 2007 to identify knowledge gaps pertaining to the potential impacts of seismic noise, with participation of the scientific community in both industry and academia. A gap analysis showed that there is a need to develop new approaches to: 1) attach instruments and transfer data; and 2) measure significant behavioural/physiological responses with limited sample sizes.

The Exploration and Production (E&P) Sound and Marine Life Joint Industry Programme has commissioned a broad range of research studies on all sources of sound produced by the offshore oil and gas industry, including seismic airguns, drilling, dredging, pile driving, construction equipment, removal of offshore structures using explosives, shipping, and others. The taxa of concern include: marine mammals, fish (all life stages), turtles, birds, and invertebrates. The primary scope of the programme's research is to describe industry sources, the known or potential effects of these sources on animals, and ways to mitigate any effects. The programme also addresses anthropogenic sounds that go beyond immediate industry needs, such as the global trend in ocean noise from all sources of human sound, the mechanisms that underlie animal injury or death from intense sound exposure, conferences discussing the latest research results, and others. Current funded research studies, including the development of tools described by Hurley (2009), fall into the following categories:

- Sound source characterization and propagation:
    - review of existing data on underwater sounds produced by the oil and gas industry;
    - standardizing methods of measuring underwater sound;
    - measuring 3D acoustic field of seismic air gun arrays; and
    - environmental assessment of marine vibrosis.
- Physical and physiological effects and hearing:
    - marine mammal noise exposure criteria;
    - marine mammal TTS tests;
    - assessing hearing capabilities of mysticete whales;
    - Minke mammal whale hearing and vocalization
    - hearing capabilities of loggerhead sea turtles;
    - blood nitrogen uptake and distribution in diving northern bottlenose dolphins;
    - models for predicting auditory tissue damage in fish; and
    - effects of noise on aquatic life.
- Behavioural reactions and biologically significant effects:
    - effects of sound on behaviour of toothed whales;
    - testing geographic positioning system/depth tags on sperm whales;
    - cetacean stock assessment in relation to exploration and production activities;
    - review of marine mammal population modeling;

    - field studies on seal foraging success; and
    - application of risk assessment for effects of sound from E&P operations.
- Mitigation and monitoring:
    - review of existing mitigation treatments;
    - analysis of marine mammal observer data;
    - testing acoustic vector sensor for 3D tracking PAM array;
    - development of open source PAM software for detection and localization of cetaceans; and
    - PAMGUARD system improvements.

In Canada, the ESRF Program has also funded several ongoing projects related to seismic impacts. Ongoing studies include:

- Seismic and invertebrates – to study the effects of seismic surveys on caged crab in the field and lobsters in a laboratory setting;
- Seismic and lobster feeding – to study the effects of airgun exposure on lobster feeding in a laboratory setting;
- Seismic and monkfish egg veils – to study the effects of exposing monkfish eggs collected from the wild to a typical airgun in a laboratory setting;
- Marine mammal observation data analysis – to analyze selected sets of marine mammal observations collected during seismic surveys on the east coast of Canada to extract information on behavioural responses; and
- Compilation of east coast whale vocalizations - to compile an electronic library of cetacean vocalizations to contribute to a database to be employed by PAM software.

3.3 DRILL MUDS

Exploratory drilling entails drilling into the geological structure to ascertain what hydrocarbon resources it contains. As Hurley (2009) describes in his review of industry practice, drilling can be conducted from a jack-up rig in shallow waters of less than about 100 m or from a semi-submersible rig or drill ship in deeper waters. The duration of exploration drilling programs typically ranges from 30-90 days. The legs of a jack up rig rest on the seabed. A semi-submersible rig/drill ship floats and is anchored in location. The well is drilled in a series of steps of decreasing size with increasing depth (up to several kilometers depth for some wells). As each step is drilled, the hole is lined with steel pipe, which is cemented in place to prevent collapse or the flow of liquids into or out of the well. As the drill bit penetrates the rock, drilling muds are used by the offshore oil and gas industry to cool and lubricate the drill bit, to balance subsurface hydrostatic pressure, and to carry drill cuttings up to the surface through drilling pipes.

Drilling muds typically contain a base fluid (water-, oil-, or synthetic-based), barite and/or bentonite (weighting agent), and chemical additives (emulsifiers, biocides, lubricants, wetting agents, corrosion inhibitors, surfactants, etc.) to enhance the mud operational properties (GESAMP, 1993). On the drilling-rig, the cuttings and muds are separated to recycle the muds while the cuttings, once treated, may or may not be discharged into the sea. In addition to the use of drilling muds and fluids to control the underground pressures when drilling, offshore oil rigs have a blowout prevention system (BOP) that is used to control the well when there is an influx of pressurized gas or oil during drilling (Hurley 2009). The BOP is a set of hydraulically-operated valves and other closure devices (rams) that seal off the well and route the wellbore fluids to specialized controlling equipment. On completion of an exploration well, the well is either removed or left in a safe condition for potential future use. If hydrocarbons are encountered, the next step is to assess the size of the reserves and extent of the reservoir. This is carried out by drilling additional appraisal or delineation wells.

The prime concerns related to discharges of drilling mud and rock cuttings are generally regarded as the burial of, or toxic effects on, seabed fauna, seabird attractions to or collisions with highly-illuminated drilling rigs, incineration during flaring/well testing, and, if the well contains hydrocarbons, a possible accidental petroleum spill (Figure 3-3). A number of mitigation measures are in place for exploratory drilling (Hurley, 2009). These include:

- conduct a pre-spud survey to verify characterization of benthic habitat, in particular the presence/absence of coral formations;
- meet or exceed the most recent version of the National Energy Board (NEB)/Canada-Newfoundland and Labrador Offshore Petroleum Board (CNLOPB)/CNSOPB Offshore Waste Treatment Guidelines and Marine Pollution (MARPOL), with regard to waste streams such as drilling muds and cuttings, deck drainage, desalinization brine, sewage and grey water (NEB et al., 2002);
- screen chemicals through the most recent version of the NEB/CNLOPB /CNSOPB 'Offshore Chemical Selection Guidelines (OCSG) for Drilling and Production Activities on Frontier Lands' and MARPOL requirements (NEB et al., 2009);
- implement well control and drilling procedures as per most recent version of the Nova Scotia Offshore Petroleum Drilling and Production Regulations;
- implement bulk transfer and hose handling procedures as per best available practice;
- minimize flaring and ensure use of high efficiency igniters as per best available practice; and
- establish a 500-m safety zone around the drilling rig at all times.

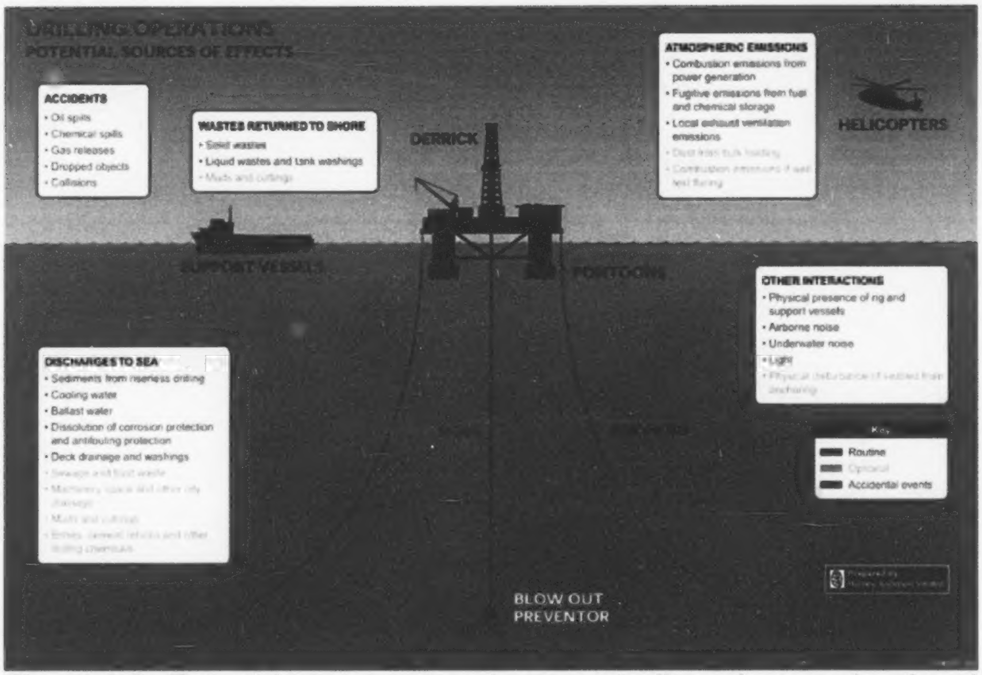

DRILLING OPERATIONS
POTENTIAL SOURCES OF EFFECTS
ACCIDENTS
• Oil spills
• Chemical spills
• Gas releases
• Dropped objects
• Collisions
WASTES RETURNED TO SHORE
• Solid wastes
• Liquid wastes and tank washings
• Muds and cuttings
DERRICK
ATMOSPHERIC EMISSIONS
• Combustion emissions from power generation
• Fugitive emissions from fuel and chemical storage
• Local exhaust ventilation emissions
• Dust from bulk loading
HELICOPTERS
SUPPORT VESSELS
PONTOONS
OTHER INTERACTIONS
• Physical presence of rig and support vessels
• Airborne noise
• Underwater noise
• Light
DISCHARGES TO SEA
• Sediments from riserless drilling
• Cooling water
• Ballast water
• Dissolution of corrosion protection and antifouling protection
• Deck drainage and washings
Key
Routine
Optional
Accidental events
BLOW OUT PREVENTOR

Figure 3-3. Potential sources of environmental effects from exploration drilling (Hurley, 2009).

Companies wishing to conduct exploratory drilling in Canadian marine waters may be required to put in place additional or enhanced environmental mitigation measures to further reduce the risk of harm to marine life (Hurley 2009). For example, additional mitigation measures that have been employed in the offshore waters of Nova Scotia include:

- focus all area lighting on the work areas of offshore platforms, as well as down-shade as much as practical to minimize marine bird attraction;
- conduct post-drilling survey to verify muds/cuttings plume dispersion modeling estimates of the environmental impact assessment, as well as the predicted zone of influence. Such a survey would include chemical analysis of sediments and benthos;
- use of heavy brine in place of barite as a weighting agent to reduce input of mercury compounds in to the marine environment;
- develop contingency measures and a response plan to address various significant weather scenarios; and
- develop a Code of Conduct for operating in proximity of the Gully MPA and Sable Island, which specifies the minimum safe working distances for aircraft and vessels nearby these special areas

Hurley (2009) also identified the following research needs to address knowledge gaps on the impact of offshore drilling operations on valued ecosystem components (VECs):

- detection of and potential behavioural effects of animals at night, in foggy conditions, or below the sea surface in the immediate vicinity of the drilling platform;
- delineation of the zone of influence and effects, if any, on marine mammal (particularly at-risk species) from noise associated with floating drilling platforms used for deep-water drilling (e.g. Scotian Slope area);
- improvements in the knowledge of critical periods (i.e. mating and calving) for marine mammals (particularly at-risk species);
- information on deep-water corals; and
- studies on the attraction of seabirds to drilling platforms, particularly during periods of low visibility (e.g. fog and darkness) and flaring.

Most drilling of offshore oil and gas wells in the North Sea, the Gulf of Mexico, and other offshore production areas is achieved with water-based drilling muds (WBM). This is due to strict regulations on discharges of oil-based mud (OBM) and synthetic-based mud (SBM) due their potential environmental impacts. Synthetic-based mud was designed to be less toxic and more environmentally-friendly than OBM. The use of SBM over WBM comes with concerns over the risk of organic enrichment and the potential persistence of synthetic-based fluid biodegradation products. These risks, however, must be weighed against the higher levels of turbidity and trace metal contaminants associated with bulk WBM disposal. Veil et al. (1995) noted that WBM use typically generates between 1100-2000 m^3 of muds and cuttings, depending on the depth and diameter of the well, compared to 300-1300 m^3 for SBM.

The use of SBM first occurred in the North Sea, although they have been curtailed since 2001 when the OSPAR[1] Commission stated that "the discharge into the sea of cuttings contaminated with synthetic fluids shall only be authorized in exceptional circumstances." Water-based mud, but not OBM or SBM, may be permitted for ocean discharge into European and U.S. offshore waters. Synthetic-based mud, but not OBM, is permitted for discharge into offshore waters of the U.S. Gulf of Mexico, with requirement of the SBM material registering as biodegradable under anaerobic conditions with indigenous micro-organisms.

Current guidelines in Canada stipulate recovery and onshore disposal of cuttings that are generated using OBM (NEB et al., 2002). Synthetic-based mud that remains from a drilling mud change-over or drilling program completion should be recovered and recycled, re-injected down-hole, or transferred to shore. The cuttings produced with WBM are allowed to be discharged into the sea, as are those produced with SBM following treatment with the best available technology (BAT). The international offshore oil and gas community believes that a concentration of 6.9 g per 100 g or less oil on wet solids can be reached through BAT practices. This discharge limit may be modified in individual circumstances where more challenging formations and drilling conditions are encountered or areas of increased environmental risk are identified. Given the relatively shallow water depth of Georges Bank, it is expected that petroleum exploration activities in the area would primarily use low toxicity WBM, with potential use of SBM as dictated by the operational requirements. It is extremely unlikely that OBM would be considered under any circumstance as per current guidelines of the CNSOPB.

---

[1] OSPAR is the mechanism by which fifteen Governments of the western coasts and catchments of Europe, together with the European Community, cooperate to protect the marine environment of the North-East Atlantic region.

The biological effects of drilling wastes can generally be thought of as being caused primarily by: (1) chemical toxicity from hazardous pollutants and biodegradation products; (2) organic enrichment of the seabed that may result in anoxic conditions; (3) physical smothering due to accumulation; and (4) physical effects on tissues (causing reduction in growth and reproduction) due to chronic exposure to very low concentrations (>0.05 mg L^{-1}) of the drilling mud compounds bentonite and barite (Cranford, 2006). Early studies on the environmental impacts of drilling wastes suggested that the fine particles of drilling muds would be quickly dissipated in high energy environments, resulting in low concentration of the wastes in areas such as the continental banks along the Canadian Atlantic coast (Neff, 1987a).

Studies in Atlantic Canada (e.g. Muschenheim et al., 1995; Muschenheim and Milligan, 1996) reported that flocculation (the adhesion of smaller particles to form large particles) and surface absorption (the adhesion of smaller particles to larger particles and/or droplets) are important processes in the transport of wastes from drilling sites (Figure 3-4). Through these processes, the bulk of the drilling muds settles quickly and accumulates on the seabed. Re-suspension and deposition processes in the benthic boundary layer tend to concentrate particulate wastes in suspension near the seabed before being dispersed by the currents (Muschenheim and Milligan, 1996). The consequences of these processes are increased sedimentation rates, oxygen depletion in the sediments, changes in sediment grain size, and an increased concentration of suspended particles in the water column. In addition, Thouzeau et al. (1991) noted that the benthos are highly sensitive to the bioaccumulation of contaminants (i.e. metals and hydrocarbons) discharged during drilling (Neff, 1987a). These observations support the hypothesis that impacts from drilling operations are most likely to affect benthic communities and that sediment impacts may persist beyond the period at which the discharge is discontinued (Cranford, 2006).

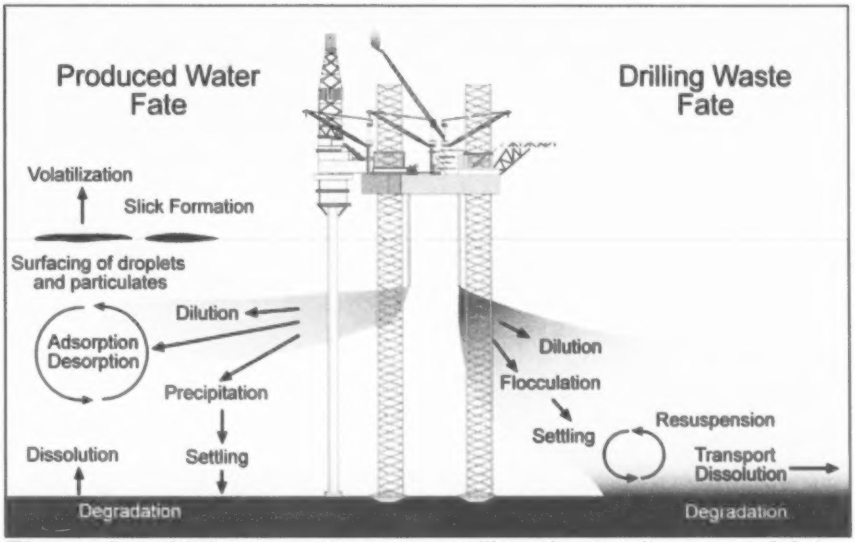

Produced Water Fate
Drilling Waste Fate
Volatilization
Slick Formation
Surfacing of droplets and particulates
Dilution
Adsorption Desorption
Precipitation
Dissolution
Settling
Degradation
Dilution
Flocculation
Settling
Resuspension
Transport Dissolution
Degradation

Figure 3-4. Major processes controlling the environmental fate of wastes from offshore oil and gas drilling and production activities (Cranford, 2006).

In terms of environmental persistence of discharged contaminants, recent DFO research studies have revealed that SBM were readily biodegradable in Atlantic marine sediments under ambient environmental conditions (Li et al., 2009b). There can be, however, a significant interference of hydrocarbon degradation by elevated metal ions when the drilling muds are recycled and reused. A trade-off of risks exists between a rapid biodegradation of the drilling muds in the sediments, which may reduce the time-scale of the removal of toxic stress caused by chemicals and the fast consumption of dissolved oxygen. This may result in hypoxia and/or anoxia in the sediment pore water (water that occupies the spaces between sediment grains on the seafloor), which can lead to the suffocation of aerobic organisms that occupy bottom sediments.

Discharged drilling muds and associated cuttings in low energy and/or shallow water systems, however, are expected to accumulate near the point of discharge (i.e. rig) where they can smother slow-moving or sessile benthic organisms. In high energy environments, such as on the top of Georges Bank, drilling muds would likely spread quickly over a larger area, thereby decreasing the risk to benthic organisms. Results of the American Georges Bank Monitoring Program have indicated that bottom currents on the top of Georges Bank are sufficiently strong to rapidly disperse materials settling from drilling sites (Neff et al., 1987; Phillips et al., 1987). The Georges Bank moratorium area includes the top of Georges Bank and surrounding deeper water areas.

3.3.1 Impacts on Marine Environment

3.3.1.1 Acute Impacts

Mortality may result from direct toxicity of discharged materials (Cranford and Gordon, 1992). Over 70 different water-based drilling mud formulations have been tested in laboratory experiments for their lethal toxicity to a variety of species. Most acute toxicity thresholds for muds and their components are much higher than concentrations expected under field conditions. Because of rapid dispersion rates and the likely use of low-toxicity WBM on Georges Bank, it is predicted that the impacted zone around drilling rigs would be limited to within a few hundred meters, or less, of the discharge pipe. Prolonged exposure (i.e. on the order of a month) to high concentrations (e.g. 10 mg L^{-1}) of bentonite and barite, however, can cause mortality to sea scallops, as well as tissue weight loss and cessation of gonad development (Cranford and Gordon, 1992, Cranford et al., 1999).

Simulations have been made with the Benthic Boundary Layer Transport (BBLT) Model for different regions of Georges Bank to determine the duration that benthic concentrations exceeded 10 mg L^{-1} at various distances along the primary drift line from a theoretical drilling rig, assuming typical release concentrations and rates of drill wastes from an exploratory well. The BBLT model was developed by DFO to predict transport and dispersion of suspended particulate drill wastes in the benthic boundary layer (Hannah et al., 1995). The model combines estimates of the current profile, bottom stress, settling velocity of the drill mud, and discharge scenario to generate estimates of drift, effective diffusivity, and concentration. Model results demonstrated that predicted waste concentrations on the bottom were not likely to cause scallop mortality, even at the release point. The longest duration for concentrations exceeding 10 mg L^{-1} occurred in the stratified region of the Bank. Values greater than 10 mg L^{-1} were predicted to occur for a period of nine days at the release site and three days at distances approximately 5 km downstream. In the frontal region, peak durations were approximately one day at the release site. These durations are much shorter than the 30 day period that caused scallop mortalities in laboratory experiments with bentonite concentrations of 10 mg L^{-1}.

A number of acute toxicity tests using aliphatic hydrocarbon-based drilling fluids that have been used on the Grand Banks have been carried out by DFO at the Northwest Atlantic Fisheries Laboratory, St. John's, Newfoundland. Exposure, which involved concentrations well above dissolved saturation levels, were as follows: Capelin larvae exposed to 0.05% oil for 72 h; Copepods exposed to 2% oil for 48 h; *Artemia* exposed to 1% oil for 24 h; ctenophores (jellyfish) exposed to 0.2% oil for 120 h; and snowcrab larvae exposed to 0.02% oil for 48 h. It was concluded that aliphatic hydrocarbons in drilling muds posed little or no ecotoxicological risk, since no differences were noted between control and exposed groups in any of the trials (Payne et al., 2001a).

3.3.1.2 Sublethal Impacts

Sublethal or chronic, long-term interactions are usually associated with the benthos, since the bulk of drilling mud wastes rapidly descend to the seabed where sessile benthic organisms become exposed (Cranford et al., 2005). For example, seabed analyses have shown barium levels above background levels out to 2500 m from the Hibernia Gravity Base Structure (GBS), while benthic community analysis indicated a localized impact (i.e. reduced biomass) within a 500 m of the GBS (Cranford et al., 2005). After drilling is completed, however, benthic impacts disappeared rapidly. Of the many benthic species present on Georges Bank, sea scallops are useful organisms to test toxicity effects of drilling mud wastes since they are very sensitive contaminants (Neff, 1987a), and preferentially filter-out and ingest the fine-grained components of the drill mud suspended in the water column (Cranford et al., 2005; Hannah et al., 2006). Cuttings, the largest component of the drilling mud discharge, are not of a size that is ingested by suspension feeders such as scallops (Cranford and Gordon, 1992).

Earlier laboratory studies estimated two kinds of sublethal effects thresholds for scallop exposure to bentonite and barite: (1) zero growth concentration (C_0) is the threshold level where there is no scallop tissue growth at or above the threshold; and (2) no effects concentration (C_1) is the threshold level where there is no significant effect on growth at or below the threshold. With respect to scallops, bentonite has a C_0 of 10 mg L^{-1} and C_1 of 2 mg L^{-1} and barite has a C_0 of 0.5 mg L^{-1} and C_1 of 0.1 mg L^{-1} (Cranford and Gordon, 1992; Cranford et al., 1999; Cranford et al., 2003). The studies demonstrated that chronic exposures resulted in the complete cessation of gonad growth in sea scallops at barite concentrations of 0.5 mg L^{-1}. Scanning electron microscope observations demonstrated evidence of damage to the ctenidia (a comb-like respiratory structure that serves as the gill) of suspension-feeding bivalves after exposure to barite at very high concentrations (Barlow and Kingston, 2001). It has been suggested that barite particles cause nutritional stress by absorption of mucus secretions, which are critical to the normal feeding and digestion processes of scallops (Cranford et al., 1999; Cranford, 2006).

Low toxicity mineral oil (LTMO) based drilling fluids (less than 0.5% aromatic hydrocarbon content) had the greatest impact on sea scallops, causing mortality within 11 days at an exposure concentration of 2 mg L^{-1} (Cranford et al., 1999). Harris (1998) conducted toxicity tests with five drilling muds that have been used and discharged in the offshore of eastern Canada. The drilling fluids include on LTMO (Shellsol DMS), two SBMs (1A-35 and Neodene 1518), and two WBMs (Silicate mud, Glycol mud). The benthic toxicity tests, using a crustacean (*Corophium volutator*) and mollusk (*Macoma balthica*), indicated that SBM and WBM were less toxic than the LTMO. Low toxicity mineral oil-based drilling fluids have not been used since 1989 in Newfoundland waters and the mid-1990s in Nova Scotia waters.

In a subsequent study, Armsworthy et al. (2005) evaluated the effect of different formulations of SBM and their concentrations on sea scallop growth (both somatic and reproductive) and mortality. There was no significant difference in the mortalities of sea scallops exposed to the different laboratory treatments. Mortality in all treatments was less than or equal to 13%. There were differences, however, in tissue growth for SBM treatments at concentrations of 0.2 mg L^{-1} and 0.9 mg L^{-1}, depending on the SBM used. Furthermore, sea scallops exposed to the SBM, at all concentrations tested, exhibited reduced clearance rates compared to the control groups. The results supported conclusions of the previous studies, which indicated that the solid fraction of the drilling fluid was largely responsible for reduced clearance rates. The reduced feeding rates, combined with reductions in food absorption, are thought to cause the observed impacts on somatic and reproductive tissue growth in scallops. That being said, it should be noted that the length and degree of exposures in controlled laboratory studies may not accurately replicate exposures found in natural settings, due to natural dilution and/or dispersion processes caused by tides and currents and variable operational discharge conditions.

Upgrades to the BBLT model since 1999 include the addition of a wave boundary layer, floc break up, and biological impacts (Drozdowski et al., 2004; Hannah et al., 2006). The wave boundary layer incorporates the combined wave-current bottom stress following Grant and Madsen (1986) and Li and Amos (2001). The floc break up capability allows the sediment to inhabit one of three settling velocity states and is bottom stress dependent. A biological impacts module, based on a growth-days-lost formulation determined from laboratory experiments on scallops (Cranford et al., 2003), was used to assess the potential risk of drilling waste discharges to sea scallop stocks on the northeastern part of Georges Bank (Cranford et al., 2003; Cranford, 2006).

Based on BBLT model runs that assumed typical operational discharge rates to be encountered during the development of an exploration well (i.e. a release of approximately 500 t of drilling mud and 2600 t of cuttings over 59 days at a drilling depth of 4600 m), the number of potential growth-days-lost by scallops was greatest at the release point and decreased with increasing distance along the primary drift line. The model results showed a potential for 0-40 days of growth inhibition over a 93-day drilling scenario (Table 3-1). Impacts were predicted to be greatest (i.e. 2-48 days of lost growth) in the vertically-stratified region around the side of the Bank (>100 m depth), which supports relatively low numbers of scallops (although dense aggregations can be found in some areas).

In the tidal front region (70-100 m depth), where scallop densities are greatest, impacts were predicted to be localized and range from 0-15 days of lost growth. It is important to note, however, that since gonadal growth appears to be affected more than somatic growth, the net effect in the frontal region may be reproductive loss. This could affect the strength of future year classes. In the central, vertically-well mixed area of the Bank (<70 m depth), which supports the lowest scallop densities, growth loss was less than one day over the drilling period. The interpretation of the results from these BBLT applications on Georges Bank depends upon several factors, including the location of the release site, distribution of scallop stocks, and time of year at which the wastes are released. Refer to the appendix in Boudreau et al. (1999) for additional information.

Table 3-1. Estimates of days of lost growth of scallops (Cranford et al, 2003). Estimates are given for two different settling velocities, which are averaged by circular areas of three different radii around the discharge point. The relative densities of scallops in the regions are also indicated.

Radius (km)	Settling Velocity ($cm\ s^{-1}$)	Region		
		Mixed	Front	Stratified
0.5	0.1	0	0	5
	0.5	2	15	40
2.0	0.1	0	0	3
	0.5	1	6	19
10.0	0.1	0	0	2
	0.5	0	3	11
Relative density of scallops		Low	Medium to High	Low to High

The Georges Bank simulations reported in Boudreau et al., (1999) and Cranford et al., (2003) have not been repeated. The most detailed simulations were carried out for North Triumph near Sable Island. Hannah et al., (2006) simulated the barite concentrations resulting from a production well drilled during October 1999 and compared the simulated and observed barium concentrations 0.5 m above the bottom measured by the environmental effects monitoring program between October 28 and November 5, 1999. The BBLT results provided a reasonable simulation of the barite concentration as a function of distance from the rig. The potential biological impact on scallops was estimated to be a few days of lost growth over scales of a few kilometres.

Hannah and Drozdowski (2005) conducted a comparison of BBLT simulations for North Triumph near Sable Island, Hibernia on the Grand Bank, and a location on the Northeast Peak (NEP) of Georges Bank. All sites are at water depths of 65-85 m. They found that the simulated barite concentrations at the NEP site were much less than at North Triumph or Hibernia. With reference to detailed simulations for North Triumph (Hannah et al, 2006), they estimated that one might expect barite concentrations on the benthos of NEP of Georges Bank of the order of 0.0001 mg L^{-1} a few weeks after discharge. These concentrations are well below the estimated no observed effects threshold limit of 2 mg L^{-1} bentonite and 0.5 mg L^{-1} barite for scallop growth (Cranford et al., 2003). Higher concentrations would be expected in the deep water around the edges of the

Bank where the currents are weaker and there is less influence from surface waves. Based on these findings, it is expected that re-running the simulations reported by Cranford et al. (2003), using the updated BBLT model, would result in lower near-bottom drill mud concentrations for locations with water depths less than about 100 m.

In the original BBLT, the model's estimated settling velocity was fixed. Boudreau et al. (1999) and Cranford et al. (2003) considered simulations using settling velocities of 0.1 and 0.5 cm s^{-1} (conservative values based on estimates of floc settling velocity) to bracket the anticipated depositional range of drill muds. The highest near bottom concentrations were obtained with the highest settling velocity of 0.5 cm s^{-1}, and those simulations formed the basis for describing potential impacts. The stress dependent settling velocity used in the most current BBLT analysis allows for the initial drill mud macroflocs (that have an assumed settling velocity of 0.5 cm s^{-1}) to break-up when the bottom stress exceeds a certain threshold value. The broken macroflocs then become incorporated into a background population of smaller microflocs that deposit at an average rate of 0.1 cm s^{-1} (refer to Hannah and Drozdowski, 2005, for details). Large tidal currents on NEP result in bottom stresses that frequently exceed the break-up stress of macroflocs. As a result, the drill mud macroflocs do not survive long enough to undergo significant deposition, so are generally characterized by the lower settling velocity. The lower settling velocity results in lower near-bottom concentrations and lower expected impacts of drilling muds on the seabed. The result is expected to hold true on the plateau of the Bank, where the tidal currents are large. This conclusion, however, may not apply to the deeper regions surrounding Georges Bank, where the currents are weaker and the influence of surface waves is less.

Cranford et al. (2005), in a summary of chronic impacts of drilling muds on major benthic organisms, indicated that low concentrations (i.e. 0.05-2 mg L^{-1}) of all major types of drilling muds (i.e. water-, low toxicity mineral oil-, synthetic-, and ester-based muds) can significantly impact the growth and reproduction of scallops (Cranford and Gordon, 1992; Cranford, 1995; Cranford et al., 1999; Armsworthy et al., 2005). Such impacts are considered to be the most critical sublethal effects on adult organisms from both ecological and fisheries perspectives (Capuzzo, 1988). According to Armsworthy et al., (2005), fine particulates in water-, synthetic-, and ester-based drilling muds (i.e. bentonite and barite) were the major cause of observed effects on feeding and digestive processes of scallops. Similar physical effects were detected in other bivalve species (Barlow and Kingston, 2001). A modelling study by Cranford et al. (2003) indicated that under certain hydrographic conditions, the routine discharge of water-based mud may impact scallop growth over an area exceeding 200 km^2. Because chemical processes such as degradation and dissolution were not included in BBLT, however the model may over estimate biological effects since the chemical concentrations may be lower in natural settings due to dissolution and degradation.

Sub-lethal effects have been observed in flounder exposed to sediments containing aromatic hydrocarbons at concentrations as low as 1 part per million, or ppm (Payne et al., 1988; Payne and Fancey, 1989). Similar studies with sediment contaminated with aliphatic hydrocarbon based drilling fluid (used in the Arctic), however, have indicated little potential to affect fish health (Payne et al., 1995). The indices studied included organ and body condition, energy reserves, liver and gill histopathology, and mixed-function oxidase (MFO) enzymes. For further evaluation of effects on health condition indices, a flatfish study was carried out to investigate the effects on parasitism in winter flounder chronically exposed for 4 months to graded concentrations of alkanes in drilling mud from the Hibernia field (Khan and Payne, 2004). The abundance of two skin parasites (*Trichodina sp* and *Gyrodactylus pleuronecti*) and a digestive tract parasite (*Steringophorus furciger*) were reduced in fish exposed to sediment-bound hydrocarbons at concentrations of 2000-6000 ppm.

A pilot, chronic toxicity study was carried out on snowcrab (Andrews et al., 2004). Crabs were exposed to elevated concentrations of drilling fluids and subsequently analyzed after one month of exposure. The indices examined included select hepatopancreatic enzymes, haematology, and hepatopancreatic histology. No differences were noted between the control and experimental groups other than a significant induction of palmityl Co-A oxidase found in the exposed animals. Palmityl Co-A oxidase is an enzyme involved in the metabolism of fatty acids. Similar effect levels were also observed in a study with lobsters that were injected with relatively high concentrations of drilling fluid (Hamoutene et al., 2004). Different aspects of lipid and protein metabolism were assessed. No effects were recorded other than an increased amount of protein found in the lobster claw muscle.

A number of dose-response studies were carried out with Microtox®, amphipods, and polychaetes to determine the direct toxicity potential of drilling source aliphatics in sediment (Payne et al., 2001b; Payne et al., 2006). Drilling muds from the Hibernia field were investigated. The study indicated that hydrocarbon concentrations of approximately 6000 ppm were required to produce direct toxicity in the various species that were investigated. Such concentrations would be expected to be confined to a range of tens of metres from cutting piles (typical of certain drilling programs found on the Grand Banks). Hurley and Ellis (2004) found that changes in the diversity and abundance of benthic organisms were detected within 1000 m of drill sites, although most changes were observed within 50-500 m. They observed that benthic communities typically returned to baseline conditions within one year of the completion of drilling. Results of these laboratory and field studies indicated a low potential for toxicity or health effects on a marine bacterium (*Vibrio fischeri*), a marine amphipod (*Rhepoxynius abronius*), Snow Crab larvae, Capelin larvae, planktonic jellyfish, Winter Flounder *(Pleuronectes americanus)*, a marine polychaete (*Neanthes arenaceodentata*) and American plaice.

3.3.1.3 Tainting Impacts

It is possible that certain metals and organic compounds contained in WBM or released with cuttings may be accumulate in various tissues of exposed organisms, even at relatively low concentrations. An important consideration is whether the accumulated contaminants may be passed along the food web and influence predators or whether they may cause tainting. If tainting was detected under field conditions by a monitoring program, the area around a rig may have to be closed to fishing for a period of time after drilling is completed. It has been shown in laboratory studies that scallops exposed to WBM have the potential to concentrate both barium and chromium in their digestive tract, as well as clay particles. It should be noted that only the scallop adductor muscle is marketed as food for humans.

In the field, measurements made during the U.S. Georges Bank Monitoring Program could not detect any uptake or accumulation of metals or hydrocarbons in ocean quahog found in the wild (Phillips et al., 1987). While the monitoring program effort did not consider scallops, as they were not found in the study area, it is also noted that taint has not been detected for any of the species tested under Canadian offshore petroleum Environmental Effects Monitoring (EEM) programs to date, where SBM or WBM have been used for drilling (Hurley and Ellis, 2004). Studies on fish and shellfish tainting have been a component of the EEM programs carried out on the Grand Banks and, to date, there has been no instances of tainting in fish collected around the Terra Nova, Hibernia or White Rose offshore facilities. Even worse case Sable Offshore Energy Project (SOEP) spill scenarios for the Scotian Shelf were not anticipated to release sufficient quantities of Scotian Shelf condensate to cause tainting of scallops or cod (S.L. Ross Environmental Research Limited, 1995).

3.3.2 Dispersion and Transport

Once discharged into the marine environment, drilling muds and cuttings may demonstrate a number of physico-chemical processes: (1) advection; (2) dispersion; (3) aggregation; (4) settling; (5) deposition onto the seabed; (6) consolidation; (7) erosion; (8) re-suspension; (9) re-entrainment; and (10) causes changes to seabed elevation. The relative impacts of these processes on the fate of drilling wastes in marine environment depends on the characteristics of the drilling wastes and physical variables of the receiving marine waters such as depth, current velocity (tidal and residual), waves, and storms. To understand the fate and effect of particles and chemicals associated with drilling wastes discharged into the ocean during drilling, a number of numerical models varying in type and complexity have been developed over the past few decades, in addition to the BBLT model described in the previous section. While some of these models only calculate the fate of drilling waste discharges by considering one or many of the physical-chemical processes listed above, other models predict the potential environmental risks associated with such discharges.

3.3.2.1 Physical Transport Models

A comprehensive review of sediment transport and drilling waste fate/transport models was conducted by Khondaker (2000). The review noted that while most of the existing models considered advection, dispersion, settling and other prevailing processes, a fully-validated model did not exist. It was concluded that the most significant modeling effort was that of Koh and Chang (1973), which forms the basis of many the subsequent modeling efforts, including the Offshore Operator's Committee (OOC) model that is generally used to model the transport of drilling wastes in the marine environment (Brandsma et al., 1980; Brandsma and Sauer, 1983; O'Reilly et al., 1989).

The OOC model can be used to simulate the behaviour of drill waste discharges from a single, submerged circular port that can be oriented in any direction by assuming a constant discharge rate. The model considers the discharge as a water-miscible fluid phase that can contain less dense particles (e.g. oil droplets) or more dense particles (e.g. drilling fluid solids or drill cuttings) relative to the ambient receiving seawater. The drilling discharge is characterized by bulk density, discharge rate, discharge pipe configuration, and settling velocities assigned to the drill mud and drill cuttings fractions. The model requires natural conditions, such as water depth, temperature, salinity, and current velocity to generate outputs such as the trajectory and shape of the discharge plume, concentrations of soluble and insoluble discharge components in the water column, and the accumulation of discharged solids on the seabed. A major limitation of the OOC model is that it does not account for re-suspension and transport of previously deposited solids. Recent applications and validation of the OOC model have been reported in a number of scientific publications (e.g. Melton et al., 2000; Brandsma, 2003; Nedwed et al., 2004; Smith et al., 2004; Pivel et al., 2009).

In the past, it was assumed that the fraction of small particles associated with drilling wastes (defined by settling velocities less than 0.01 cm s^{-1}) would readily dissipate to negligible concentrations on the energetic offshore banks of eastern Canada. Drilling wastes, however, have been found to form particle aggregates 0.5-1.5 mm in diameter, which exhibit settling velocities that are much higher than their individual component particles. As a result, it is now thought that the bulk of drilling mud discharges may deposit out of suspension much more rapidly than previously believed, resulting in increased accumulation on the seabed (Muschenheim et al., 1995; Muschenheim and Milligan, 1996; Milligan and Hill, 1998). Muschenheim and Milligan (1996) suggested that the resuspension and deposition processes of drill wastes in the benthic boundary layer could concentrate particulate wastes near the seabed before they are dispersed by currents and waves. Although the aggregation of drill wastes (also termed 'flocculation') has been observed on the Scotian Shelf off Sable Island at the Panuke and Cohasset oilfield drilling sites (Muschenheim and Milligan, 1996), the degree to which it occurs about offshore petroleum sites throughout Atlantic Canada remains unknown. During two separate surveys at the Hibernia offshore petroleum production site, flocculation was observed during one survey but not another.

Results of physical oceanographic and drilling waste behaviour studies have been used in the application of plume descent models for discharged wastes (e.g. Andrade and Loder, 1997) and in the development and application of a novel model for drilling waste dispersion and drift in the benthic boundary layer. The plume descent model simulations have confirmed rapid initial dilution of discharged wastes, but have also indicated that the fraction reaching the benthic boundary layer can vary greatly by location depending on local oceanographic conditions such as currents, stratification, and water depth. Simulations of Georges Bank predict that regional and temporal variations in physical oceanographic processes have a large influence on the potential zone of influence of any discharged drilling wastes (Gordon et al., 2000).

The BBLT model was developed at the Bedford Institute of Oceanography to predict the transport and dispersion of particulate drilling wastes in the benthic boundary layer. The BBLT model has been widely used in the Atlantic Canadian offshore region to assess the potential impact zones of drilling waste discharged during offshore petroleum drilling activities (Drozdowski et al., 2004). The model assumes that all the discharged materials enter the benthic boundary layer and thus neglects the mechanism of plume surfacing. The primary mechanisms modeled by BBLT are shear dispersion, mud flocculation, and break-up, drift, and vertical mixing. The model has been used to simulate the dispersion of drilling wastes around drilling platforms under typical exploration drilling scenarios on Georges Bank (Hannah et al., 1995; Gordon et al., 2000). Hannah et al. (2003) also used BBLT to predict the drift and dispersion of suspended drilling muds near North Triumph on Sable Island Bank during a drilling program in 1999. The model results were in agreement with the very low concentrations (generally less than 1 $\mu g\ L^{-1}$) of barium observed in the water column during the subsequent EEM iteration. Further evaluation of the sensitivity of the BBLT model to settling velocity data and comparisons to other existing models have been undertaken by Niu et al. (2008) and Niu et al. (2011).

Other modeling efforts include SizeCUT, a numerical model that considers contamination by various agents in drill cuttings released under restricted open water conditions (IESL, 2003). The model considers both the jet of the drilling discharge and individual particles, after a transitional stage. The kinetic energy of the jet gradually decreases during its evolution. Once the kinetic energy is diminished, individual particles are subjected to the gravitational force and to the influence of currents and turbulent motions. Fang et al. (2008) developed a model to predict the formation of underwater cutting piles. Although the model considered the effects of water depth, current velocity, cutting properties (e.g. size distribution, density, and sphericity), and water properties (e.g. density and viscosity), its application in an oceanographic environment was limited by the need to use constant current conditions. ASA (2009) developed the MUDMAP model based on a random-walk particle tracking approach to simulate the dispersion of drilling wastes. As with the OOC model, MUDMAP also accounts for three stages of movement, based on the Koh and Chang (1973) approach, to predict the transport and dilution of drilling fluid discharges.

The application of circulation and dispersion models has provided means to assess the potential spatial scale of dispersion of drilling waste discharges. It should be noted, however, that models are simulations, open to assumptions and simplifications, and caution is warranted in their application to decision making. Special care must be taken, since parameters related to the settling velocity of different sized particles under various conditions are not known, and this can lead to major variability in predictions. Regional and temporal variations in physical oceanographic processes, which determine the degree of dilution, suspension, dispersion, and drift of drill wastes in the benthic boundary layer have a large affect on their potential zone of influence.

3.3.2.2 Physico-chemical Models

Two drilling waste transport models have been developed to predict the fate of chemicals associated with drilling waste discharges: PROTEUS and DREAM. Sabeur and Tyler (2000) described PROTEUS, which considers the dispersion of drill muds and cuttings as a distribution of solid particles with given size, density, chemical content, and settling velocities through three three-dimensional hydrodynamic flow, turbulent advection, and passive diffusion models. PROTEUS also models the chemical transformations that occur following discharge using a decoupled geochemical model. This is achieved by associating chemical mass with particles, representative of the solid or dissolved phase. The chemical mass carried by each particle is updated in time by taking into account mass loss through various processes such as degradation, volatilization, and adsorption/dissolution between solid and dissolved phases.

The second comprehensive model that has been extensively used to study both the physical transport of drilling wastes and corresponding chemical transformations is the Dose-related Risk and Effect Assessment Model (DREAM) described by Rye et al. (2006a; 2006b) and Rye et al. (2008). The DREAM model uses a Lagrangian particle tracking approach. The model generates particles with associated properties (such as mass of various compounds, densities, and settling velocities) at the discharge points which are transported with currents and turbulence in the sea. The particles can also represent state variables, such as gas bubbles, droplets, and dissolved and/or solid matter. The DREAM model incorporates a near-field plume model in order to account for the descent of the cutting/mud plume. The model determines the 'depth of trapping' or 'sinking' of a plume by considering governing factors such as current velocity and stratification. In WBM, most of the added chemicals are mainly assumed to dissolve in the water column, while the dissolution rate of chemicals may be lower for OBM and SBM. The chemicals may have a high capacity for adsorption to organic matter found in the sediment or water column.

For chemicals in the drilling wastes, the DREAM model calculates the water column concentrations as a function of time and space. The model considers the degradation but not the adsorption to ambient suspended matter. The particulate matter in the water column is calculated similar to the chemicals except the degradation is omitted. The model can also estimate the water column concentration of heavy metals originating from particulate matter based on equilibrium partitioning. For the sediments, the DREAM model can calculate four stressors: the deposit of drill cuttings/mud that may cause burial effects; the change of grain size distribution that may favour other species; chemical concentration in the sediment layer that may cause toxic effects; and biodegradation of chemicals that may cause oxygen depletion. The DREAM model is used extensively in the North Sea for environmental risk assessments. A sample DREAM model prediction of two of the four sediment stressors is shown in Figure 3-5.

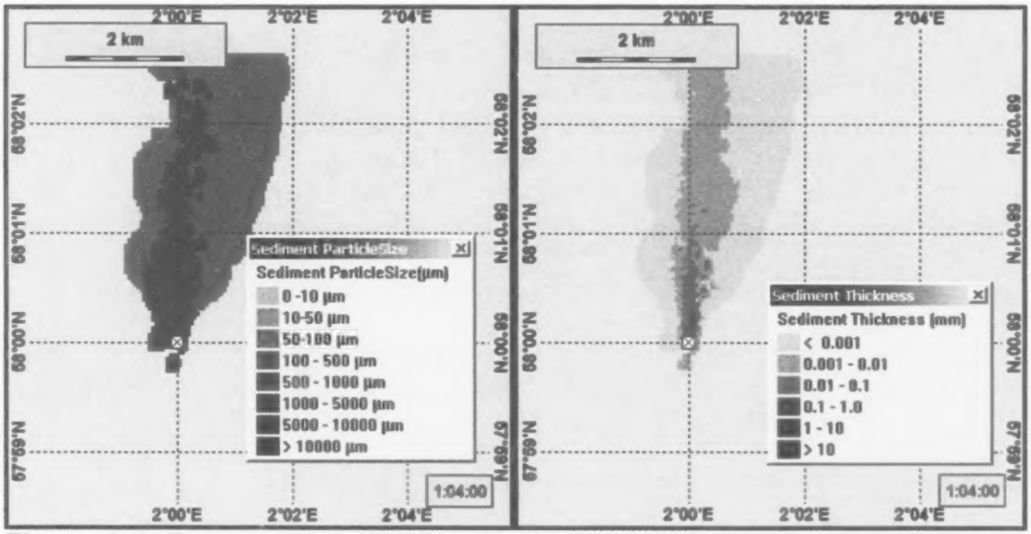

2 km
2°00'E
2°02'E
2°04'E
58°02'N
58°01'N
58°00'N
57°59'N
Sediment ParticleSize
Sediment ParticleSize(µm)
0 -10 µm
10-50 µm
50-100 µm
100 - 500 µm
500 - 1000 µm
1000 - 5000 µm
5000 - 10000 µm
> 10000 µm
1:04:00
2 km
Sediment Thickness
Sediment Thickness (mm)
< 0.001
0.001 - 0.01
0.01 - 0.1
0.1 - 1.0
1 - 10
> 10
1:04:00

Figure 3-5. Example of a DREAM model simulation of two sediment stressors from a discharge in the North Sea: grain size (left panel) and depositional layer thickness (right).

3.3.2.3 Risk Assessment Models

The integration of risk assessment modules into physical transport/fate and effect models will enable the calculation of potential risks to Georges Bank from drilling waste discharges. For example, the BBLT model incorporates a component to predict biological effects on sea scallops based on laboratory toxicity tests with different concentrations of drilling wastes (Cranford et al., 2003). Chemical processes such as degradation and dissolution have not been included in BBLT, and chemical concentrations may be lower in field conditions due to dissolution and degradation. Since drilling waste may induce impacts in both the water column and sediments, the DREAM model calculates the effects from six potential stressors.

For the water column, the two stressors are the toxicity of chemical substances and physical effects of suspended clay particles. The sediment stressors include toxicity of chemical substances, burial of organisms, oxygen depletion, and change in sediment structure. The model uses the ratio of predicted environmental concentration (PEC) and predicted no-effect concentration (PNEC) to first evaluate the risk associated with individual stressors and then determine the overall risk from all stressors expressed as an environmental impact factor (EIF) (Altin et al., 2008; Neff, 2008; Rye et al., 2008; Singsaas et al., 2008; Smit et al., 2008). A sample DREAM model prediction of risks from two of four sediment stressors is shown in Figure 3-6. The contribution of individual sediment stressors to total EIF for a test case is illustrated in Figure 3-7.

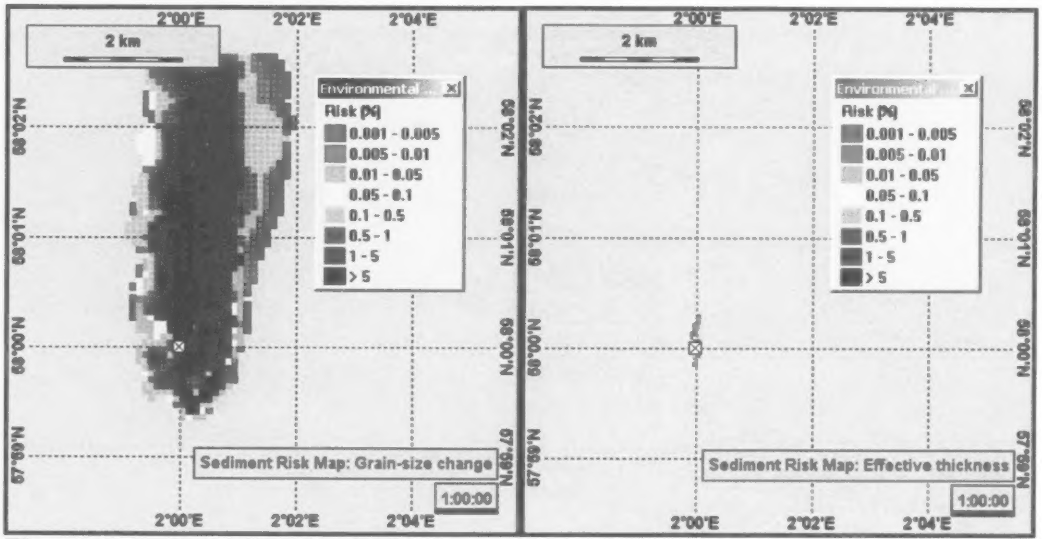

2°00'E
2°02'E
2°04'E
2 km
Environmental
Risk (%)
0.001 - 0.005
0.005 - 0.01
0.01 - 0.05
0.05 - 0.1
0.1 - 0.5
0.5 - 1
1 - 5
> 5
58°02'N
58°01'N
58°00'N
57°59'N
Sediment Risk Map: Grain-size change
1:00:00
Sediment Risk Map: Effective thickness

Figure 3-6. Example of a DREAM model simulation of risk from a discharge in the North Sea: effects of grain size change (left panel) and effects of burial (right panel).

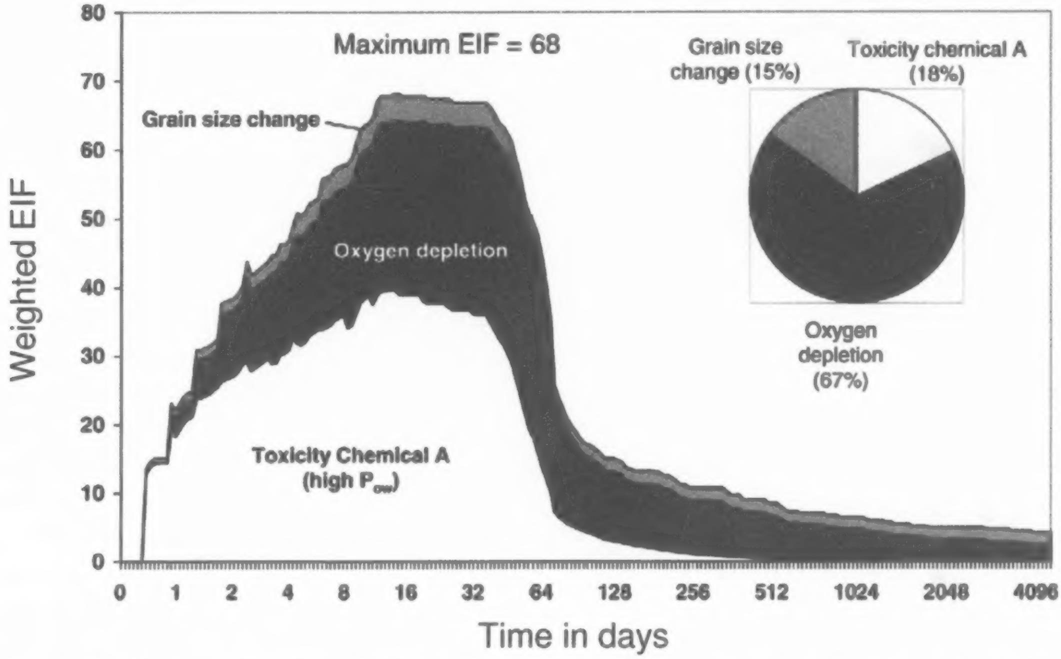


Figure 3-7. Contribution of four sediments stressors in the North Sea to total environmental impact factor (EIF) (from Singsaas et al., 2008).

3.3.3 Environmental Effects Monitoring

Environmental Effects Monitoring programs are a requirement of long-term offshore petroleum development projects approved by the NEB, CNSOPB, and CNLOPB (e.g. Cohasset-Panuke, Sable Offshore Energy, Hibernia, and Terra Nova). They are used as: 1) follow-up to comprehensive studies and screenings pursuant to the *Canadian Environmental Assessment Act*, 2) verify the accuracy of project Environmental Impact Assessments (EIA), 3) determine the effectiveness of mitigation measures, and 4) identify unforeseen environmental problems, as they emerge, to enable a timely management response. Hurley and Ellis (2004) reviewed EEM programs on the east coast of Canada, which have been largely focused on the effects of drilling waste discharged to the marine environment (i.e. drilling mud and drill cuttings), as this was considered the primary environmental concern during exploration and development drilling operations. Results were compared to those from foreign offshore sites (e.g. Gulf of Mexico and North Sea).

3.3.3.1 Detection Zones

Most of the early knowledge regarding the dispersion and effects of muds/cuttings discharged into the marine environment was gained through seabed studies conducted at North Sea offshore petroleum sites that began operations in the 1970s using diesel based OBMs. Davies et al. (1988)

concluded that chemical tracers associated with OBMs could be documented out to 800-4000 m distances from the drilling centre. They also noted a transition zone in benthic diversity and community structure that occurred between 200-2000 m from the drilling centre. Subsequent observations over an extended period indicated that the spatial extent and magnitude of effects of OBM cuttings discharge on benthic communities was highly variable.

Olsgard and Gray (1995) documented, over a period of six to nine years after conclusion of drill cuttings discharge, the spread of sediment contamination so that nearly all sample stations 2000-6000 m from the drill site showed evidence of elevated hydrocarbon metals. Olsgard and Gray (1995) also noted that effects on benthos persisted longer than the elevated hydrocarbons, suggesting that metals or other components in the drill cuttings contributed to long term biological effects. For three different oil fields, Olsgard and Gray (1995) documented the spatial extent of sediment that exhibited elevated hydrocarbon and metal (primarily barium) content, which ranged from 10 to more than 100 km^2. In another study, Daan et al. (1996) indicated that localized hydrocarbon contamination and biological effects were detectable up to eight years after completion of drilling programs. Consequently, in light of its environmental persistence and toxicity, the discharge of OBM cuttings has largely been prohibited by offshore regulatory agencies, in favour of WBM, SBM, and LTMO formulations.

Based on chemical indicators of drilling muds, such as barium in association with total petroleum hydrocarbons (TPH), large development projects (e.g. Hibernia and Terra Nova) with several wells at the same location exhibit larger zones of detection (out to 8000 m along the major current axis) than single well developments (maximum 1000 m) at similar water depths (80 m) on the Grand Banks (e.g. White Rose H-20 and N-30) and the Scotian Shelf (e.g. SOEP North Triumph #1). The spatial and temporal extent of detectable discharged drilling wastes was influenced by differences in the number of well, volume of discharges, mud types, current speed and direction, water depth, or sediment mobility at the drilling location. For example, strong physical transport processes, such as the highly-mobile sandy bottom sediments on shallow areas of Sable Bank (less than 40 m), could account for the relatively small contaminant zone around the multiple-well Cohasset-Panuke and SOEP Venture and Thebaud sites (Ross et al., 2003). Two different classes of SBMs have been used for drilling in eastern Canada; that is, the paraffin-based Pure Drill IA-35 used on the Grand Banks and internal olefin-based NovaPlus used on the Scotian Shelf. Discharges of the paraffin-based SBM may have been distributed farther in ocean currents because of differences in oil-on-cuttings concentration and/or the floatation properties of paraffin compared to the olefin-based SBM that tends to settle out of suspension much more quickly as cohesive, well-defined mounds (Hurley, 2000).

The EEM observations made in Atlantic Canada are similar to those found in other offshore petroleum regions. A review of 18 studies of drilling wells that discharged WBM indicated that barium was observed up to 1000-3000 m around the discharge location and up to 8000 m along the major flow axis (Houghton et al., 1980; Mariani et al., 1980; Meek and Ray, 1980; Menzie et al., 1980; Ray and Meek, 1980; CSA, 1986; Boothe and Presley, 1989; Jenkins et al., 1989). One notable exception, based on a study of eight exploration wells discharging WBM, documented that drilling fluid solids can be transported over long distances, up to 35-65 km, to regional depozones, albeit at low concentrations (Bothner et al., 1985; Neff et al., 1989a). Synthetic-based muds found in sediments documented from nineteen case studies were detected over a more localized area than for WBM. The detection limits for background values ranged from 100-2000 m about the discharge location. Increases in other metals known to be associated with drilling fluids (e.g. arsenic, cadmium, chromium, copper, mercury, lead, and zinc) have been observed with distance from single well sites. Elevated concentrations are generally found over a more spatially-limited range of 250-500 m about the drilling centre, in comparison to that for barium. Exceptions, however, have been reported. For example, chromium was detected up to 1000-2000 m from sites on the continental shelf (CSA, 1986) and at deeper locations greater than 80 m water depth in the Gulf of Mexico, while concentrations of cadmium and mercury above biological effect threshold limits were found to exist several years after drilling had completed (Kennicutt et al., 1996).

3.3.3.2 Biodiversity and Abundance

Changes in the diversity and abundance of benthic organisms have been detected within 1000 m of drill sites, most commonly within the 50-500 m range. Results are consistent for both literature review case studies and for the Canadian EEM data. This scale of effects apply to wells discharging SBM or WBM and for multiple or single wells drilled at the same site. Beyond the bottom area covered by the cuttings pile, benthic communities generally returned to baseline conditions within one year after completion of drilling discharges.

With the disposal of WBMs, biological effects have routinely been detected at distances within 1000 m of drill sites (DOI, 1977; Lees and Houghton, 1980; Menzie et al., 1980; Montagna and Harper, 1996; Hurley and Ellis, 2004). Effects include alterations to benthic community structure, including changes in abundance, species richness (number of species), and diversity. Impacted taxa include annelids, molluscs, echinoderms, and crustaceans. Changes have been attributed to purely physical alterations in sediment texture and to platform-associated effects more frequently than to toxic effects. Studies of benthic community change around single exploration wells suggest that communities generally returned to baseline conditions one year after the completion of drilling. A report of effects beyond 1000-2000 m around single exploration wells, as a reduction in the epibenthic coverage of suspension feeding bryozoan communities on hard bottom substrates (CSA, 1989), has been questioned due to the difficulty in distinguishing effects related to natural variability over time over that from changes in community composition with respect to drilling activities.

The area of detection and scale of biological effects resulting from SBM cuttings discharged were smaller than that resulting from the release of WBM. Biological impacts associated with the release of SBM cuttings were generally detected at distances of 50-500 m from well sites (Bakke et al, 1990; Smith and May, 1991; Candler et al., 1995; Daan et al., 1996; Terrens et al., 1998; Orentas, 2000; Hurley and Ellis, 2004). Patin (1999) also noted that biological effects in the form of structural changes in benthic communities can be found up to 1000 m from platforms. These changes lead to either depressed or enhanced species diversity in the near field (MMS, 1995). While recovery of benthic communities were generally documented to occur within one year of completion, one case study documented that benthic species richness and abundance were reduced at a distance of 50 m two years after exploratory drilling was completed (Candler et al., 1995).

3.3.3.3 Toxicity and Biological Effects

Heavy particles within drilling wastes tend to settle near the discharge site and can form a pile on the seafloor. There is potential for biological effects of these cutting piles that include smothering of benthic communities and artificial reef effects as the piles attract marine organisms and provide substrate for epifaunal animals such as crabs (Forteath et al., 1982; Hurley and Ellis, 2004). Beyond the cutting pile, observed impacts of drilling wastes have generally been attributed to chemical toxicity or organic enrichment, although there was evidence in the EEM studies that fine particles in drilling wastes contributed to the effects observed around drilling platforms. This observation is consistent with laboratory studies conducted on filter feeding sea scallops, which indicated that physical interference by bentonite and barite particles in drilling wastes could affect growth and reproduction at environmentally-relevant concentrations (Cranford et al., 2005).

Results of EEM studies conducted in Atlantic Canada showed that the effects of drill waste on the benthic community varied with the volume of muds and cuttings discharged and proximity to the point of discharge. In areas closest to the platform, benthic organisms can be physically smothered under cuttings piles (e.g. Newburn-23). Beyond the cuttings piles, species diversity and abundance of infauna can either be depressed (e.g. Terra Nova- within 200 m of discharges from multiple wells), or enriched (e.g. SOEP North Triumph No.1- within 1000 m of discharges from a single well), but appear to return to baseline levels within one year of the completion of drilling discharges. In one case, seasonal variations may have masked potential effects of drilling discharges on infauna (e.g. Cohasset-Panuke 1993). Naturally low diversity in some locations (e.g. EnCana H-08) also makes it difficult to discern changes in the benthic community.

A number of early warning bioindicators including fish condition indices, skin and organ lesions, liver and gill histopathology, and levels of MFO enzymes, were studied in American plaice at the Terra Nova site on the Grand Banks (Mathieu et al., 2005). Chronic toxicity studies showed limited bioaccumulation of polycyclic aromatic hydrocarbons (PAH) in flounder exposed to sediments containing high levels of petroleum hydrocarbons. Under Canadian east coast EEM programs in the field, no early warning health effects have been observed with biochemical and/or histopathological indicators of chemical stress in American plaice and a variety of shellfish species (Payne et al., 1995; Cranford et al., 2001; Hurley and Ellis, 2004). Mixed-function oxygenase induction was not observed in fish collected around some platforms in the Gulf of Mexico (McDonald et al., 1996), although it is noted that the reference fish also contained high levels of PAH metabolites suggesting extensive background contamination by hydrocarbons at the reference site.

In contrast, enzyme induction has been observed in a number of adult fish species, as well as fish larvae around rigs in the North Sea, compared to nearby reference sites (Davies et al., 1984a; Stagg et al., 1995; Stagg and McIntosh, 1996). Histopathological effects have also been observed in fish and shellfish in association with some oil developments in the Gulf of Mexico (Galloway et al., 1981; Grizzle, 1986; Wilson-Ormond et al., 1994). The effects observed in fish in both the North Sea and the Gulf of Mexico may be related to production waters. Peterson et al. (1996) documented readily detectable changes in benthic meiofauna and macrofauna, but failed to detect evidence of exposure or sublethal impacts on demersal fish species. They concluded that the mobility of fish species, the relevant scales of environmental change, and their negligible exposure to hydrocarbons and other contaminants were the primary reasons for a lack of documented effects in the fish species studied.

3.3.3.4 Bioaccumulation and Taint

Body burden concentrations of TPH in sea scallops extended as far as 2600 m about Terra Nova, but were not detected in sea scallops at SOEP NT#1. Total petroleum hydrocarbon was also detected in blue mussels about COPAN and SOEP NT#1, but not in snow crabs about SOEP NT#1 or American plaice about Terra Nova and Hibernia. Bioavailability and bioaccumulation of hydrocarbons and other oil components depend upon the balance and ratios between the rate of their input into the organisms, the efficiency of biochemical transformation in organs and tissues, and the rate of excretion (Patin, 1999). Benthic invertebrates, especially bivalves, usually have an increased ability to accumulate oil due to their high filtration rates, contact with bottom sediments, and less-developed and less-active enzyme and metabolic systems when compared with fish systems (Patin, 1999).

Taint was not detected for any of the species tested in the Canadian EEM programs, except for blue mussels at COPAN, which discharged more toxic LTMO muds. Mathieu (2002) noted that although valuable for assessing fish health, quality, and marketability, chemical analyses of tissues can be inadequate as a measure of fish health because: 1) many chemicals do not accumulate in body tissues to any degree yet they can be quite damaging; 2) only a limited number of toxic chemicals in complex nature can be measured; 3) the toxicity of many chemicals may not be due to the chemicals measured but by degradation products which are not readily measured; and 4) there are few dose-response experimental studies linking body burdens of chemicals to effects.

Biodegradation processes may influence the level of impact from SBM discharges. Synthetic fluids are likely to produce substantial sediment oxygen demand when discharged in the amounts typical of offshore drilling operations. At present, there is disagreement among the scientific community as to whether slow or rapid degradation of synthetic base fluids is preferable. Highly-biodegradable materials will deplete oxygen more rapidly than slow degrading materials. Rapid biodegradation, however, reduces the exposure period of aquatic organisms to materials that may bioaccumulate or have toxic effects. Currently, the United States Environmental Protection Agency (U.S. EPA) believes rapid degradation is preferable because seafloor recovery has been correlated with disappearance of the SBM base fluid.

3.4 PRODUCED WATER

Produced water is the wastewater that is generated during the production and processing of offshore oil and gas. Formation water is sea water or fresh water that has been trapped with oil and natural gas in porous sedimentary rock formations between layers of impermeable rock within the Earth's crust for millions of years (Collins, 1975). When a hydrocarbon reservoir is penetrated by a well, produced fluids may contain significant volumes of this formation water, in addition to the oil, natural gas, and/or gas liquids. In some oil fields, fresh water, brine/seawater and 'treatment' chemicals may also be injected into a reservoir to enhance both recovery rates and the safety of operations. These chemicals may be recovered along with oil and gas during production (Neff, 2002; Veil et al., 2004). Produced water (formation and injected water and process chemicals that are recovered) represents the largest volume waste stream in oil and gas production operations on most offshore platforms (Stephenson, 1991; Krause, 1995). For instance, produced water may account for 80% of the wastes and residuals produced from natural gas production operations (McCormack et al., 2001).

The ratio of produced water to oil equivalents (WOR) from a well varies widely from essentially zero to more than 10 (91% water and 9% oil). The average world-wide WOR is about 2 to 3. In general, the volume of produced water usually increases with the age of the well (Henderson et al., 1999). In nearly depleted fields, production may be 98% produced water and 2% fossil fuel (Stephenson, 1992; Shaw et al., 1999). On the Canadian East Coast, the produced water discharged by the Cohasset field on the Scotian Shelf outnumbered oil by a ratio of 2:1 during its life. The Hibernia field on the Grand Banks is expected to follow a similar trend (Ayers and Parker, 2001). In 2003, an estimated 667 million tonnes of produced water were discharged offshore throughout the world, including 21.1 million tonnes to offshore waters of North America (mostly the U.S. Gulf of Mexico) and 358-419 million tonnes to offshore waters of Europe (mostly the North Sea) (OGP, 2004; Garland, 2005).

These are underestimates of actual discharges because reporting of production to OGP (2004) ranged from 11-99% in the seven regions of the world being monitored. In terms of discharge capacity, it is generally reported that the total amount of water produced from gas fields is much smaller than that from oil production fields. While many gas fields discharge less than 10 m^3 d^{-1} of produced water, most oil fields discharge hundreds or even thousands of cubic metres of produced water per day (OGP, 2002). In 2009, the Venture field on the Scotian Shelf was discharging 100-600 m^3 d^{-1} of produced water (personal communication, ExxonMobil). A considerable amount of concern has recently been raised over the disposal of produced water from production operations as its release is continuous, in comparison to the episodic release of contaminants associated with the disposal of drill muds and fluids during the drilling of exploration and production wells.

3.4.1 Chemical Composition

Produced water is a complex mixture of organic and inorganic chemicals in both dissolved and particulate phases. The physical and chemical properties of produced water vary widely depending on the age, depth, and geochemistry of the hydrocarbon-bearing formation, as well as the chemical composition of the oil and gas phases found in the reservoir. Typical chemicals found in produced water include inorganic salts, metals, radioisotopes, and a wide variety of organic chemicals (Table 3-2). Because no two produced waters are alike, region specific studies should be conducted to address the environmental risks that may be associated with its discharge.

Table 3-2. Concentrations (mg L^{-1}) of several classes of naturally-occurring metals and organic chemicals in produced water found world-wide (Neff, 2002).

Chemical Type	Concentration* (mg L^{-1})
Organic Chemicals:	
Total benzene, toluene, ethylbenzene, and xylenes (BTEX)	0.068-578
Total organic acids	≤0.001-10,000
Total organic carbon	≤0.1->11,000
Total phenols (primarily C_0-C_5-phenols)	0.4-23
Total polycyclic aromatic hydrocarbons (PAH)	0.04-3.0
Total saturated hydrocarbons	17-30
Total steranes/triterpanes	0.14-0.175
Inorganic Chemicals:	
Ammonia	14-246
Arsenic	0.000004-0.32
Barium	≤0.001-2,000
Cadmium	0.0000005-0.49
Chromium	≤0.000001-0.39
Copper	≤0.000001-55
Iron	≤0.0001-465
Lead	≤0.000001-18
Manganese	0.0002-7.0
Mercury	≤0.000001-0.075
Nickel	≤0.000001-1.67
Nitrate	0.6-15.8
Orthophosphate	0.1-6.6
Salinity (mostly sodium and chloride)	<2000-> 300,000
Sulfate	≤1.0-8,000
Sulfide	0 - 140
Total radium (pCi L^{-1})	0-5,150
Zinc	0.000005-200

*Note: Many of the high concentrations reported for metals may be anomalous due to matrix interferences from high concentrations of dissolved salts that may be found in the produced water (Neff, 1987b). The highest concentrations are extremely rare. Concentrations of most chemical constituents listed above, measured by modern, accurate, analytical methods, reside in the lower part of the concentration ranges listed above

3.4.1.1 Total Organic Carbon

The concentration of total organic carbon (TOC) in produced water ranges from less than 0.1 to more than 11,000 mg L^{-1}. It is highly variable from one location to another (Table 3-2). Produced water from Hibernia has a TOC content of approximately 300 mg L^{-1} (Ayers and Parker, 2001). Produced water from wells off Louisiana contains 67-620 mg L^{-1} of dissolved TOC and 5-127 mg L^{-1} of suspended TOC (Veil et al., 2005). A large fraction of the dissolved TOC may be found in colloidal suspension (Means et al., 1989).

3.4.1.2 Organic Acids

Much of the TOC in produced water consists of a mixture of low molecular weight carboxylic acids, such as acetic acid, propionic acid, butyric acid, and valeric acid (Means and Hubbard, 1987; Somerville et al., 1987; Barth, 1991). These low molecular weight organic acids are readily synthesized, as well as biodegraded, by bacteria, fungi, and plants. They represent nutrients for phyto- and zooplankton growth. The most abundant organic acid typically found in produced water is acetic acid. The abundance of the various organic acids typically decreases with increasing molecular weight (Fisher, 1987). Many heavy crude oils contain high concentrations of naphthenic acids and cycloalkane carboxylic acids (with one or more saturated 5- or 6-ring carbon structures). They are slightly water soluble and, when present in a heavy crude oil, also are present in the associated produced water. Organic acids are produced by hydrous pyrolysis or microbial degradation of hydrocarbons in the hydrocarbon-bearing formation (Borgund and Barth, 1994; Tomczyk et al., 2001).

3.4.1.3 Petroleum Hydrocarbons

Petroleum hydrocarbons are the organic components of greatest environmental concern in produced water. Petroleum hydrocarbons are classified into two groups: saturated hydrocarbons and aromatic hydrocarbons. The solubility of petroleum hydrocarbons in water decreases as their size (i.e. molecular weight) increases. Aromatic hydrocarbons are more water-soluble than saturated hydrocarbons of the same molecular weight. The hydrocarbons in produced water appear in both dissolved and dispersed (i.e. oil droplets) forms. Current regulatory guidelines for produced water discharge in Canada are based on petroleum hydrocarbon content. In Canada, the hydrocarbon content of produced water must be reduced to acceptable levels pursuant to the 'Offshore Waste Treatment Guidelines (2002)' prior to discharge into the ocean (NEB et al., 2002). The minimum regulated standard for the treatment and/or disposal of wastes associated with the routine operations of drilling and production installations offshore Canada is a 30-day weighted average of oil in discharged produced water of 30 mg L^{-1}, which is coupled with a 24-hour arithmetic average of oil in produced water that shall not exceed 60 mg L^{-1}.

Existing oil/water separators, such as hydrocyclones, are quite efficient in removing oil droplets from produced water. As a result, petroleum hydrocarbons discharged to the ocean in produced water are typically low molecular weight aromatic hydrocarbons, as well as smaller amounts of saturated hydrocarbons found in the dissolved phase. Since there are no clean-up procedures that are completely effective, treated produced water still contains some dispersed oil droplets in the size range of 1-10 μm in diameter (Johnsen et al., 2004). The droplets contain most of the higher molecular weight, less soluble saturated and aromatic hydrocarbons. The most abundant hydrocarbons in produced water are the one-ring aromatic hydrocarbons, benzene, toluene, ethylbenzene, xylenes (benzene, toluene, ethylbenzene, and xylenes are known as BTEX), and low molecular weight saturated hydrocarbons. Xylenes may be present in produced water from different sources and at concentrations as high as 600 mg L^{-1} (Table 3-2). Benzene often is the most abundant BTEX compound in produced water, followed by toluene. Because BTEX is extremely volatile, it is lost rapidly during produced water treatment, by air stripping and during initial mixing of the plume in the ocean (Terrens and Tait, 1996).

Polycyclic aromatic hydrocarbons, are defined as hydrocarbons containing two or more fused aromatic rings. These are the petroleum hydrocarbons of greatest environmental concern in produced water because of their toxicity and persistence in the marine environment (Neff, 1987b; Neff, 2002). Concentrations of total PAH in produced water typically range from approximately 0.04-3.0 mg L^{-1} and primarily consist of 2- and 3-ring PAH compounds such as naphthalene, phenanthrene, and their alkyl homologues (Table 3-3). Higher molecular weight, 4- through 6-ring PAH compounds rarely are detected in properly-treated produced water. When present, they are typically associated with dispersed oil droplets (Johnsen et al., 2004).

3.4.1.4 Phenols

Concentrations of total phenols in produced water usually range from 0.4-23 mg L^{-1} (Table 3-2). Measured concentrations of total phenols in produced waters from the Louisiana Gulf coast and the Norwegian Sector of the North Sea range from 2.1-4.5 mg L^{-1} and 0.36-16.8 mg L^{-1}, respectively (Neff, 2002: Johnsen et al., 2004). The most abundant phenols in these produced waters are phenol, methylphenols, and dimethylphenols. Alkylphenol ethoxylate (APE) surfactants, containing octylphenols and nonylphenols, are sometimes used in the production system to facilitate the pumping of viscous or waxy crude oils. If the surfactant degrades some alkylphenols may dissolve in the produced water. Because of the toxicity of the more highly-alkylated phenols as endocrine disruptors, alkylphenol APE surfactants have been replaced in applications where the surfactant or, its degradation products, may reach the environment in significant amounts (Getliff and James, 1996).

Table 3-3. Concentrations (in µg L^{-1}) of individual polycyclic aromatic hydrocarbons (PAH)s found in produced waters of the Scotian Shelf and Grand Banks, compared to the U.S. Gulf of Mexico (DOE, 1997; OOC, 1997), Indonesia (Neff and Foster, 1997), and Thailand (Battelle, 1994).

Compound	Gulf of Mexico	Indonesia	Thailand	Scotian Shelf[1]	Grand Banks[2]
Acenaphthene	ND-0.10	ND-1.3	ND	ND	ND
Acenaphthylene	ND-1.1	ND	ND	1.3	2.3
Anthracene	ND-0.45	0.17-0.63	ND	0.26	ND
Benz(a)anthracene	ND-0.20	0.06-0.43	ND	0.32	0.60
Benzo(a)pyrene	ND- 0.09	ND	ND	ND	0.38
Benzo(b)fluoranthene	ND-0.03	ND-0.31	ND	ND	0.61
Benzo(e)pyrene	ND-0.10	0.05-0.81	ND	ND	0.83
Benzo(ghi)perylene	ND-0.03	ND	ND	ND	0.17
Benzo(k)fluoranthene	ND-0.07	ND	ND	ND	ND
Biphenyl	0.36-10.6	2.3-6.9	NA	ND	ND
Chrysene	ND-0.85	0.10-1.4	ND	ND	3.6
C_1-Chrysenes	ND-2.4	0.41-5.6	0.16	ND	6.3
C_2-Chrysenes	ND-3.5	0.69-8.8	ND	ND	18.8
C_3.Chrysenes	ND-3.3	0.52-6.4	ND	ND	6.7
C_4-Chrysenes	ND-2.6	ND-2.4	ND	ND	4.2
C_1-Fluorenes	0.09-8.7	3.3-9.2	3.55	3	23.7
C_2-Fluorenes	0.20-15.5	2.2-13.3	4.03	0.35	4.8
C_3-Fluorenes	0.27-17.6	1.9-15.6	2.24	ND	ND
C_1-Fluoranthenes/ Pyrenes	ND-2.4	1.0-4.3	0.34	0.43	5.8
C_2-Fluoranthenes/ Pyrenes	ND-4.4	0.93-7.3	NA	ND	9.1
C_1-Naphthalenes	4.2-73.2	63.5-100	207	499	186
C_2-Naphthalenes	4.4-88.2	43.4-126	166	92	163
C_3-Naphthalenes	2.8-82.6	19.3-81.3	71.1	17	97.2
C_4-Naphthalenes	1.0-52.4	6.4-36.2	21.0	3.0	54.1
C_1-Phenanthrenes	0.24-25.1	4.2-29.5	4.06	1.30	45.0
C_2-Phenanthrenes	0.25-31.2	3.8-31.5	3.43	0.55	37.1
C_3-Phenanthrenes	ND-22.5	3.0-25.4	1.91	0.37	24.4
C_4-Phenanthrenes	ND-11.3	1.3-11.9	ND	ND	13.2
Dibenz(a,h)anthracene	ND-0.02	ND	ND	ND	0.21
Fluoranthene	ND-0.12	0.13-0.24	ND	0.39	0.51
Indeno(1,2,3-cd)pyrene	ND-0.01	ND	ND	ND	ND
Naphthalene	5.3-90.2	45.6-156	395	1512	131
Perylene	0.04-2.0	ND-0.09	ND	ND	ND
Phenanthrene	0.11-8.8	9.3-29.5	3.12	4.0	29.3
Pyrene	0.01-0.29	0.12-0.49	ND	0.36	0.94
Total PAHs	**40-600**	**230-745**	**888**	**2148**	**845**

ND: Not detected

NA: Not analyzed

[1] Thebaud (DFO-Centre for Offshore Oil, Gas and Energy Research (COOGER), Unpublished Data)

[2] Hibernia (DFO-COOGER, Unpublished Data)

3.4.1.5 Salinity and Inorganic Ions

The salt concentration (i.e. salinity) of produced water can range from a few parts per thousand (‰) to that of a saturated brine of approximately 300‰, compared to the typical salinity of seawater of 32-36‰ (Rittenhouse et al., 1969; Large, 1990) (Table 3-2). Most produced water has salinities greater than that of seawater and, are therefore, more dense than seawater (Collins, 1975). Produced water contains the same salts as seawater, with sodium and chloride the most abundant ions. Sulfate and sulfide concentrations usually are low, allowing barium and other elements that form insoluble sulfates and sulfides to be present in solution at high concentrations. However, if seawater, which naturally contains a high concentration of sulfate (i.e. approximately 29 millimolar, or mM), is injected into the formation for production purposes, barium and calcium may be precipitate onto the inner surface of production pipes as a scale coating. Ammonium ions may be present in some produced waters at highly-elevated concentrations, which may induce inhibitory (i.e. toxic) and/or stimulatory (e.g. eutrophication) responses from resident biota (Anderson et al., 2000).

3.4.1.6 Metals

Produced water may contain several metals in solution. The type and concentration of metals present in produced waters from different sources is variable, depending on the age and geology of the formations from which the oil and gas are produced (Collins, 1975). A few metals may be present in produced waters from different sources at concentrations substantially higher (i.e. 1000-fold or more) than their concentrations in clean natural seawater. The metals most frequently present in produced water at elevated concentrations, relative to those in seawater, include barium, iron, manganese, mercury, and zinc (Neff et al., 1987b) (Table 3-4). Typically, only a few of these metals are present at elevated concentrations in a particular produced water sample. On the east coast of Canada, elevated concentrations of barium, iron and manganese have been reported in close proximity to the Hibernia platform located on the Grand Banks (Yeats et al., 2011).

Table 3-4. Concentrations (µg L^{-1}) of metals found in produced water from the Scotian Shelf and the Grand Banks, compared to the northwestern Gulf of Mexico and Norwegian Sector of the North Sea (Neff, 2002). Concentrations found in seawater are also included.

Metal	Scotian Shelf[1]	Grand Banks[2]	Gulf of Mexico[3]	North Sea[4]	Seawater
Arsenic (As)	90	<10	0.5-31	0.96-1.0	1-3
Barium (Ba)	13,500	301-354	81,000-342,000	107,000-228,000	3-34
Cadmium (Cd)	<10	<0.02-0.04	<0.05-1.0	0.45-1.0	0.001-0.1
Chromium (Cr)	<1-10	<1	<0.1-1.4	5-34	0.1-0.55
Copper (Cu)	137	<5	<0.2	12-60	0.03-0.35
Iron (Fe)	12,000-28,000	1,910-3,440	10,000-37,000	4,200-11,300	0.008-2.0
Lead (Pb)	<0.1-45	0.09-0.62	<0.1-28	0.4-10.2	0.001-0.1
Manganese (Mn)	1,300-2,300	81-565	1,000-7,000	NA	0.03-1.0
Mercury (Hg)	<10	NA	<0.01-0.2	0.017-2.74	0.00007-0.006
Molybdenum (Mo)	NA	<1	0.3-2.2	NA	8-13
Nickel (Ni)	<0.1-420	1.7-18	<1.0-7.0	22-176	0.1-1.0
Vanadium (V)	NA	<0.1-0.6	<1.2	NA	1.9
Zinc (Zn)	10-26,000	<1-27	10-3,600	10-340	0.006-0.12

[1] SOEP/DFO
[2] Combined results from Hibernia and Terra Nova (DFO-COOGER, Unpublished Data)
[3] Combined results from seven platforms
[4] Combined results from 12 platforms

Injecting seawater into a well during production may increase the concentration of sulfate, which is present in seawater at a concentration of approximately 900 mg L^{-1}, in the formation water causing barium to precipitate as barite ($BaSO_4$). This lowers the concentration of free barium found in the produced water (Stephenson et al., 1994). Several other metals in produced water, particularly radium isotopes, may co-precipitate with barium and reduce their concentrations. Formation water is anoxic and iron and manganese may be present in solution at high concentrations. When these formation waters are brought to the surface and exposed to the atmosphere, the iron and manganese precipitates out as iron and manganese oxyhydroxides. Several other metals in produced water may co-precipitate with iron and manganese and be dispersed, adsorbed to, or complexed with very fine, solid hydrous iron and manganese oxides in the receiving waters (Lee et al., 2005b; Azetsu-Scott et al., 2007). Zinc and, possibly lead, may be derived in part from galvanized steel structures in contact with the produced water or with other waste streams that may be treated in the oil/water separator system.

3.4.1.7 Radioisotopes

Naturally occurring radioactive material (NORM) is present in produced water in many parts of the world. The most abundant NORM radioisotopes in produced water are the natural radioactive elements radium-226 (^{226}Ra) and radium-228 (^{228}Ra). Radium is derived from the radioactive decay of uranium and thorium associated with certain rocks and clays found in the hydrocarbon reservoir (Reid, 1983; Kraemer and Reid, 1984; Michel, 1990). ^{226}Ra, which has a half-life of 1601 years, is an α-emitting daughter of uranium-238 and uranium-234. ^{228}Ra, which has a half-life 5.7 years, is a β-emitting daughter of thorium-232. Surface waters of the ocean have ^{226}Ra and ^{228}Ra concentration values of 0.027-0.040 picocuries per liter (pCi L^{-1}) and approximately 0.005 pCi L^{-1}, respectively (Santschi and Honeyman, 1989; Nozaki, 1991).

Concentrations of the combined total ^{226}Ra and ^{228}Ra found in produced water from oil, gas, and geothermal wells along the Gulf of Mexico coast range from less than 0.2 pCi L^{-1} to 13,808 pCi L^{-1} (Kraemer and Reid, 1984; Neff et al., 1989b) (Table 3-5). There is no correlation between the concentrations of the two radium isotopes in produced water, because of their different origins in the geologic formation. Concentrations of radium and other NORM found in produced water from elsewhere in the world, other than the northern Gulf of Mexico, are generally low, with the activity of Ra^{226} and Ra^{228} usually less than 200 pCi L^{-1} (Table 3-5). Preliminary studies on produced water samples collected in Atlantic Canada indicate radium isotope levels several orders of magnitude above normal seawater concentrations. Due to the level of natural dispersion, however, only ambient background concentrations can be detected in seawater samples collected in the area of production platforms located on the Grand Banks and the Scotian Shelf (Nelson, 2009).

Table 3-5. Activities (pCi L^{-1}) of radium-226 (^{226}Ra) and radium-228 (^{228}Ra) found in produced water from different locations (Neff, 2002). Activities found in seawater are also included.

Offshore Location	Radium-226 (^{226}Ra)	Radium-228 (^{228}Ra)	Reference
Scotian Shelf	1.2	9.2	Nelson, 2009
Grand Banks	33.0	229.7	Nelson, 2009
Cook Inlet, Alaska	<0.4-9.7	NA	Neff, 1991
Louisiana Gulf Coast	ND-1,565	ND-1,509	Kraemer and Reid, 1984
North Sea	44.8	105	Stephenson et al., 1994
Offshore U.S. Gulf of Mexico	91.2-1,494	162-600	Hart et al., 1995
Santa Barbara Channel, California	165	137	Neff, 1997
S. Java Sea, Indonesia	7.6-56.5	0.6-17.7	Neff and Foster, 1997
Texas	0.1-5,150	NA	Fisher, 1987
Seawater	0.027-0.04	0.005	Santschi and Honeyman, 1989; Nozaki, 1991

3.4.1.8 Production Chemicals

Large numbers of specialty additives, or treatment chemicals, are available for use in the production system of a well that aid in the recovery and pumping of hydrocarbons, protect the production system from corrosion, and facilitate the separation of oil, gas, and water (Table 3-6). These include biocides, scale inhibitors, emulsion-breakers, and gas-treating chemicals. Many of these chemicals are more soluble in oil than in produced water, so remain in the oil phase. Others are water-soluble, concentrate in produced water, and are disposed with it. The point in the production stream where the chemical is added influences the amount that may be discharged to the ocean or re-injected into the reservoir with the produced water. Treatment chemicals are used in direct response to a problem and are not added where there is no demonstrated need. The use of treatment chemicals is managed through the use of best management practices such as the Offshore Chemical Selection Guidelines (OCSG) and regulatory compliance effluent toxicity testing protocols.

Table 3-6. Typical use concentration (ppm) of production chemicals used on North Sea oil and gas platforms and the estimated amounts (t y^{-1}) discharged to the ocean (Johnsen et al., 2004).

Chemical	Concentration (ppm)	Phase	Discharge (t y^{-1})
Biocide	10 – 200	Water	81
Coagulants and flocculants	<3	Water	197
Corrosion inhibitor	25 – 100	Oil	216
Emulsion Breaker	10 – 200	Oil	9
Gas treatment chemicals	Variable	Water	2846
H_2O/O_2 scavenger	5 – 15	Water	22
Scale inhibitor	3 – 10	Water	1143

3.4.2 Treatment

Most environmental regulatory agencies in countries that have significant offshore oil and gas production place limits on the concentrations of petroleum, usually measured as total oil and grease, that can be present in produced water discharged to the ocean. Table 3-7 gives examples of limits on oil and grease set by various countries. Produced water intended for ocean disposal is usually treated on the platform or at a shore treatment facility to meet regulatory limits. The objective of oil-water-gas treatment on an offshore platform is to produce stabilized crude oil and gas for pipeline or tanker transport to shore facilities and to generate a produced water that meets discharge requirements (if discharged to the ocean) or is suitable for reinjection into the producing formation or other geologic formation (Bothamley, 2004).

Table 3-7. Monthly average and daily maximum concentrations (mg L^{-1}) of total oil and grease allowed in produced water discharged to the ocean, as permitted by various offshore petroleum producing countries (Veil, 2006).

Country	Monthly Average (mg L^{-1})	Daily Maximum (mg L^{-1})
Canada	30	60
Brazil	---	20
Mediterranean Sea	40	100
Nigeria	40	72
OSPAR (NE Atlantic)	30	---
U.S.	29	42
Western Australia	30	50

It is necessary to treat produced water before ocean discharge to avoid the harmful effects that the chemicals in waste waters may have on the receiving environment. Treatment removes solids and non-aqueous liquids from the waste water, including dispersed oil, suspended solids, scales, and bacterial particles, as well as corrosive gases such as carbon dioxide (CO_2) and hydrogen sulphide (H_2S). Experience with produced water treatment for ocean disposal by the offshore oil industry has shown that, if dispersed oil is removed, concentrations of dissolved hydrocarbons are reduced to acceptable levels (Ayers and Parker, 2001). If the treated waste water is intended for disposal in freshwater, recycled for steam generation for the various thermal enhanced oil recovery (EOR) technologies, or for reinjection into the formation, most of the dissolved salts also should be removed. Salt removal is not necessary if discharge is into the ocean.

The produced water oil/gas/water mixture may be processed through devices to separate the three phases from each other. The types of equipment used on many platforms to remove oil and grease from produced water include mechanical and hydraulic gas floatation units, skimmers, coalescers, hydrocyclones, and filters (Otto and Arnold, 1996). Chemicals may be added to the process stream to improve the efficiency of separation. The combination of mechanical and chemical treatments is effective in removing volatile compounds and dispersed oil from the produced water, but they are ineffective in removing dissolved organics and inorganics. Even with the most advanced separation equipment, the oil/water separation is not completely efficient.

Produced water from offshore oil and gas wells is treated to remove volatile hydrocarbons, dispersed petroleum, and suspended solids to the extent afforded by current waste water treatment technology. The global average concentration of total petroleum hydrocarbons in produced water discharged offshore in 2003 was 21 mg L^{-1}, with a range for different geographic regions of 14-39 mg L^{-1} (OGP, 2004) (Figure 3-8). The quality of produced water discharge is primarily a function of the strictness and degree of enforcement of environmental discharge regulations. In Canada, the formulation of regulatory guideline values for produced water discharge is an adaptive process that promotes the development of improved EEM programs and takes into consideration the level of environmental risk, BAT for mitigation measures, and social-economic benefits.

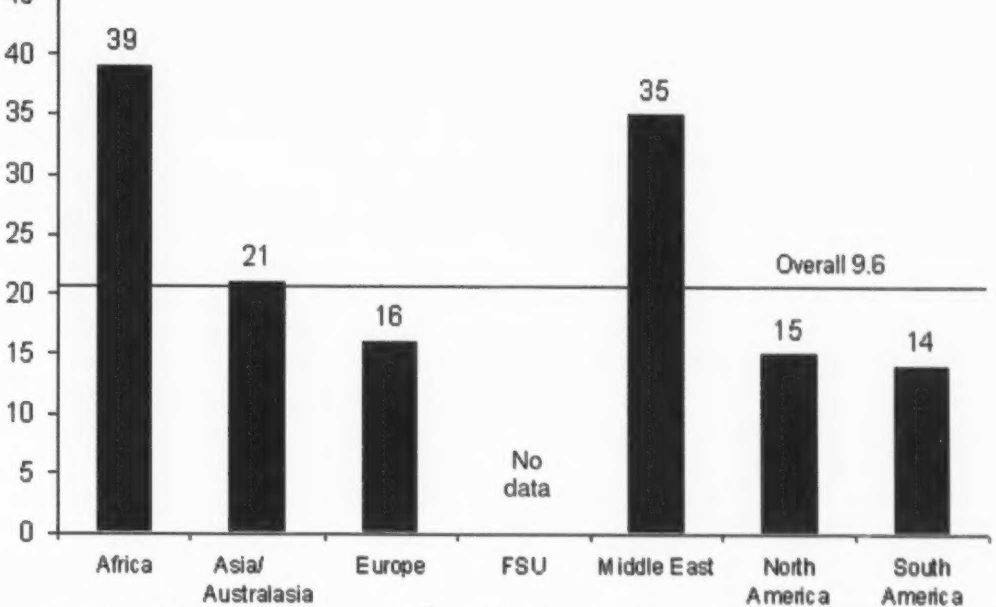


Figure 3-8. Concentration (mg L^{-1}) of total petroleum hydrocarbons (TPH) in produced water discharged offshore in several parts of the world. The overall average TPH concentration in produced water from both onshore and offshore petroleum production is 9.6 mg L^{-1} (solid line). Data are not available for the former Soviet Union (OGP, 2004).

3.4.3 Fate of Discharge in the Ocean

Treated produced waters on offshore platforms are typically discharged above or below the sea surface once regulatory compliance concentrations are achieved. The location of subsurface discharge pipes may range at depths of 10-100 m. Saline produced waters are usually as dense as or denser than seawater and disperse below the sea surface, diluting rapidly upon discharge into well-mixed marine waters. Low salinity produced water may form a plume on the sea surface and dilute more slowly (Nedwed et al., 2004). Dispersion modeling studies of the fate of produced water differ in specific details, but all predict a rapid initial dilution of discharges by 30- to 100-fold in the first few tens of metres of the outfall. This is followed by a slower rate of dilution at greater distances (Terrens and Tait, 1993; Strømgren et al., 1995; Brandsma and Smith, 1996; Smith et al, 2004). When discharge volumes of buoyant or neutral-density produced water are very high, dilution may be slower. Factors that affect the rate of dilution of produced water include discharge rate, height above or below the sea surface, ambient current speed, turbulent mixing regime, water column stratification, water depth, differences in density (as determined by temperature and total dissolved solids concentration), and chemical composition between the produced water and receiving seawater.

3.4.3.1 Plume Dispersion Models

Brandsma and Smith (1996) modeled the fate of produced water discharged under typical Gulf of Mexico conditions. They used two discharge rates: 115.7 m^3 d^{-1}, which is the median flow rate for offshore discharges to the Gulf of Mexico, and 3,975 m^3 d^{-1}, which is the maximum allowable discharge rate from a single discharge pipe to the Gulf of Mexico. The effluent was a hypersaline brine that was discharged at a temperature of approximately 29 ºC. As a result, it was denser than the ambient seawater and tended to sink. For a median produced water discharge rate of 115.7 m^3 d^{-1}, the predicted concentration of produced water in the plume 100 m down-current from the discharge point ranged from 0.043-0.097% produced water depending on ambient current speed. At the higher discharge rate, dilutions at 100 m down-current from the discharge ranged from 0.18-0.32%produced water depending on current speed. For large produced water discharges, such as the discharge from the platform *Irene* off Santa Barbara, California, which has a discharge rate of 6,359 m^3 d^{-1}, the modeling work by Brandsma (2001) estimated a rapid decrease of plume centerline concentration to approximately 2% produced water at 100 m from the discharge point.

High dilution rates for produced water appear to be typical. In a modeling study by Terrens and Tait (1994), using the OOC model to predict the behaviour of a 14,000 m^3 d^{-1} discharge from the *Halibut* platform in Bass Strait, Australia, the produced water was reported to be dynamically-indistinguishable due to a high degree of initial dilution. Dilutions of seawater to produced water ranged from 100:1 to 252:1. At 6 km, the dilution factors were approximately 13,000:1 for suspended oil and 18,000:1 for dissolved oil. Skåtun (1996) used a BJET model to study the near-field mixing of warm (i.e. 32 ℃) produced water of high salinity (84 ppt) released from a platform in the Gulf of Mexico. At 103 m downstream of the release point, a dilution factor of 400:1 was reported in the presence of a 0.15 m s^{-1} current. The physical dispersion models of projected discharges from the Sable Offshore Energy Project (SOEP) wells located on the Scotian Shelf of Canada also indicated a rapid dilution of discharge to non-acute toxic levels within short distances of the discharge points (SOEP, 1996).

The OOC model is used for predicting the short term fate of produce water discharge and the other models described above only consider near field mixing. It is important, however, to also study the long-term, far-field transport of produced water. Hodgins and Hodgins (1998) studied the dispersion of produced water from the Terra Nova floating production, storage, and offloading (FPSO) vessel off the East Coast of Canada using the Three-dimensional Updated Merge (UM3) model coupled with a particle tracking based far-field model. For a maximum discharge of 18,000 m^3 d^{-1}, the estimated worst-case initial dilution was 5:1. As the pooled effluent near the hull of the FPSO is carried away by the ambient currents, the far field model predicted a minimum secondary dilution of

5:1, which yields a combined total dilution of 25:1 after the plume has been dispersed a few hundred metres from the FPSO.

The same modeling concept was also applied to the White Rose development off the East Coast of Canada (Hodgins and Hodgins, 2000). For the discharge of produced water with a density of 728 kg m^{-3} at a maximum discharge rate of 30,000 m^3 d^{-1} from a 14 inch diameter pipe at 5 m below sea surface, the near-field model of UM3 estimated an initial bulk dilution of 35:1 (Hodgins and Hodgins, 2000). The far-field dispersion simulation showed that the 1% impact line (concentration greater than 0.1 mg L^{-1} or dilution less than 400:1 for at least 1% of the time) extend from 1.8-3.2 km. Similar results were also described by AMEC (2006), who predicted near-, intermediate-, and far-field dilution rates using the U.S. EPA Visual Plumes model (Baumgartner et al., 1994), USACE CDFate model (Chase, 1994) and an advection/diffusion model. Assuming a maximum flow rate of 6400 m^3 d^{-1} of produced water from the Deep Panuke facility (not yet in production) to be located in the offshore of Nova Scotia, the model estimated a dilution of 70:1 at 500 m from the proposed discharge centre and 400:1 at 2 km from the discharge centre.

The ASA MUDMAP™ model (refer to Spaulding, 1994) was run by Burns et al. (1999) to study the dispersion of produced water from the Harriet oil field off the western Australian coast. Based on an average discharge of 8000 m^3 d^{-1} and total oil concentration of 5.9-16 mg L^{-1}, the model predicted that the produced water plume would exhibit oil concentrations of 0.006 mg L^{-1} near the discharge centre to 0.00016 mg L^{-1} at approximately 8 km downstream. Zhao et al. (2008) integrated a random walk based particle tracking model with the Princeton Ocean Model (POM) for fast prediction of future dispersion and risks of produced water discharges. For a produced water discharge at 882 m^3 h^{-1} from the Hibernia platform off the East Coast of Canada, the model predicted a lead concentration of 0.002 μg L^{-1} at approximately 5.3 km south of the platform. An overestimation of dilution and underestimation of pollutant concentration may result from the Zhao et al. (2008) method due to an omission of near-field buoyant jet behaviors. Accuracy of the model could be improved by coupling a near-field model with the particle tracking model using the method described by Zhang (1995) and Niu et al. (2011).

For a hypothetical study of the produced water discharged from the Terra Nova FPSO, Mukhtasor et al (2004) estimated a mean concentration of 0.5% of the initial concentration at approximately 225 m from the discharge. The 95%-tile concentration from their analysis at the same location was approximately 2.25% the initial concentration. Similar approaches were also used by Niu et al. (2009a) to study the effects of surface waves on the dispersion of produced water. Since the models of Mukhtasor (2004) and Niu et al. (2009a) can only be used for a limited number of discharge conditions, Niu et al. (2009b) expanded the same approach into a more general model (PROMISE) which can be used over a wider range of discharge and environmental conditions. A validation study of the

PROMISE model has been reported by Niu et al. (2009c) and good agreement was found between model predictions and laboratory measurements.

As is evident in this overview, during the last two decades a significant amount of effort has been put forward to model the dispersion of produced water plumes in the marine environment. Researchers from different disciplines have approached the problem from different perspectives and developed models of varying degrees of sophistication. Produced water plume dispersion models have evolved from the simple steady state near-field, short term dilution models to comprehensive coupled hydrodynamic/dispersion models that predict both the near- and far-field dispersion processes in 3D non-steady state conditions. Although the dispersion models are now able to simulate the near-field mixing process very well and, predict the far-field mixing process reasonably well, they are still limited in their ability to predict the fate of the various chemical components in produced water.

3.4.3.2 Chemical Fate and Transport Models

In the majority of physical transport models the chemicals in the produced water stream are treated as passive tracers. Dye injection tracer studies of produced water plumes (e.g. DeBlois et al., 2011) are based on the same assumptions. The drawback of using dyes is that they may not become fully integrated into the produced water plume, resulting in an inaccurate prediction of transport of the various contaminants that react chemically and separate from the plume. Based on recent studies by Lee et al. (2005b) and Azetsu-Scott et al. (2007), consideration must also be given to the chemical reactivity that may influence the subsequent fate, transport, and effects of the contaminants of concern in the produced water following its discharge.

To study the fate of benzene and naphthalene in produced water discharges from the SOEP Thebaud platform on the Scotian Shelf, Berry and Wells (2004a; 2004b) used the CORMIX model (refer to Doneker and Jirka, 2007) to determine the exposure pathways and potential compartment interactions and then a Level III fugacity model (refer to Mackay, 1991) to study the distribution of benzene and naphthalene among environmental medias, such as water, suspended particles, fish, and sediments. The study indicated that the average water column bulk concentration of benzene and naphthalene over a 1 km by 1 km area were 5.28×10^{-6} µg g^{-1} and 8.49×10^{-7} µg g^{-1}, respectively, for a maximum discharge rate of 211.7 m^3 d^{-1}. Since the CORMIX model predicted that the produced water plume may not be fully mixed in the selected compartments, the fugacity model may underestimate the concentration in the produced water plume and overestimate the concentration outside of the plume.

In a study by Smith et al. (1996), a coupled model was used to simulate the transport of produced water from the Pertamina/Maxus petroleum operation area in the Java Sea, Indonesia. The CORMIX model was first used to predict effluent dispersion and the results were then integrated into a PISCES model (refer to Turner et al., 1995) to study partitioning, degradation, and volatilization. The model predicted that mercury at 500 m away from the discharge centre was approximately 5.25-522 ppt and arsenic was approximately 5-12 ppb. At 3000 m downstream, the mercury concentration decreased to 65 ppb and arsenic to 3 ppb. The use of separate dispersion and chemical models cannot account for the dynamics that change the chemical concentrations following discharge. Murray-Smith et al. (1996) applied the particle-based model TRK to the Clyde offshore petroleum platform in the United Kingdom sector of the North Sea. Besides physical dispersion, the model allowed a first order degradation to simulate biodegradation or other removal processes. The study found that the initial dilution was rapid and a minimum dilution factor with seawater of 300-3000 times within 100 m of discharge can be achieved. Further away, the physical dilution was less rapid and other removal processes such as biodegradation may become important. The model predicted an overall dilution (including biodegradation) of 1000-16000 at 1 km from the discharge centre.

Reed et al. (1996) described a PROVANN model for the simulation of 3D transport, dilution, and degradation of chemicals associated with produced water discharges from one or more simultaneous sources. The model included various transport processes such as adsorption/dissolution kinetics, entrainment, and dissolution of oil droplets, volatilization, degradation, and deposition from the water column. For two platforms off of Trondheim, Norway, the simulation showed that the naphthalene concentration at the edge of the plume 40 km downstream after 50 days was extremely low (approximately 0.00006 ppb). The simulation also found that the inclusion of degradation is clearly an important factor in modeling long term exposure. Reed et al. (2001) described a Dose-related Risk and Exposure Assessment Model (DREAM) for simulation of produced water discharges (Figure 3-9). The model has been recently used by Durell et al. (2006) to model the fate of various PAHs in produced water discharged from the Ekofisk and Tampen fields in the Norwegian sector of the North Sea. For Ekofisk region stations, the model predicted naphthalene concentrations in the range of 5-29.6 nanograms per litre (ng L^{-1}). The total PAHs for this region were 5.55-32.3 ng L^{-1}. The predicted concentrations in the Tampen region were higher than the Ekofisk region, with naphthalene ranging from 5-311 ng L^{-1} and total PAHs ranging from 5.55-344 ng L^{-1}.

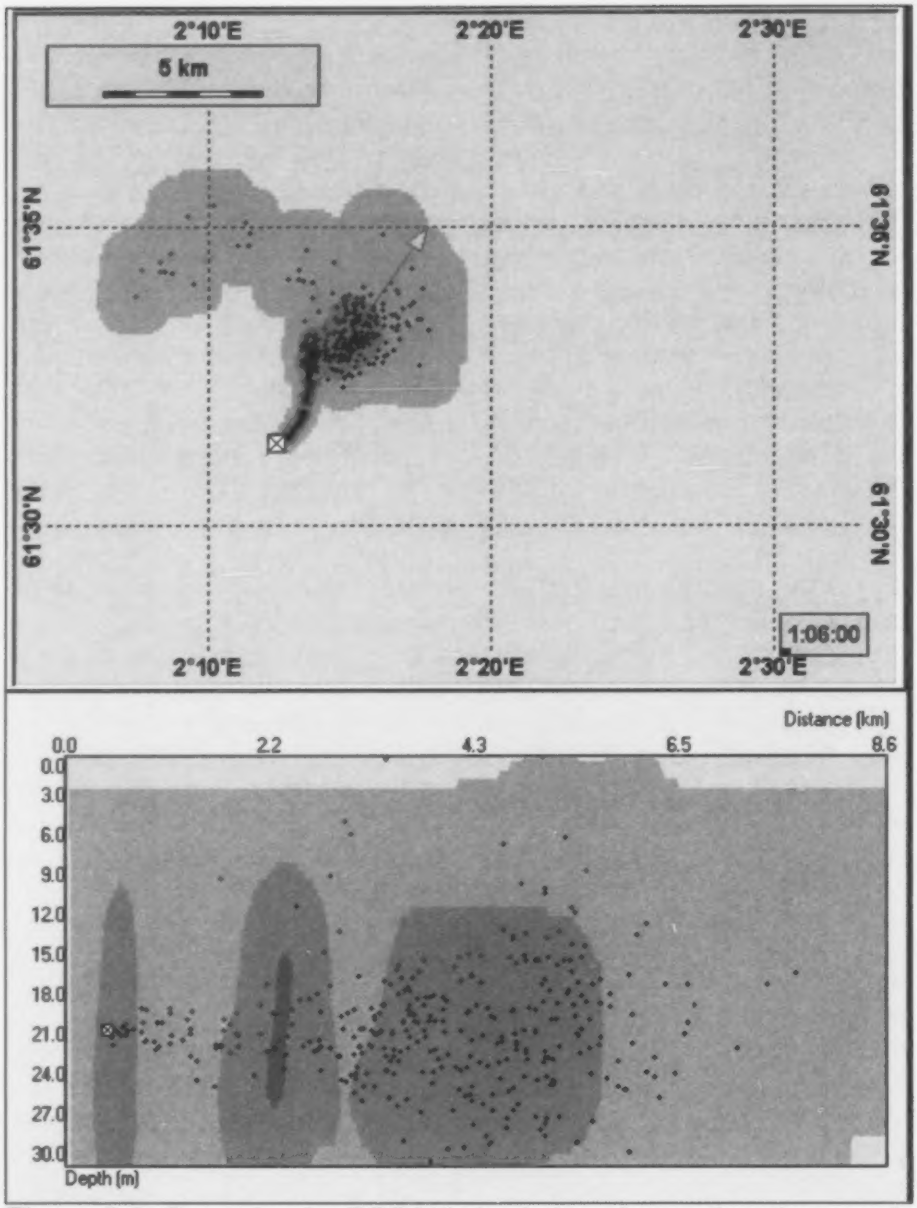

2°10'E
2°20'E
2°30'E
5 km
61°35'N
61°30'N
1:06:00
Distance (km)
0.0
2.2
4.3
6.5
8.6
0.0
3.0
6.0
9.0
12.0
15.0
18.0
21.0
24.0
27.0
30.0
Depth (m)

Figure 3-9. Example of a DREAM simulation of a produced water plume: aerial view (top) and cross-sectional profile (bottom).

3.4.3.3 Field Measurements of Produced Water Dilutions

Field measurements of produced water dilutions are highly variable but confirm the predictions of modeling studies that dilution is typically rapid. In 1993, Continental Shelf Associates reported that radium-226 from a 1070 m^3 d^{-1} produced water discharge at depth of 18 m in the Gulf of Mexico was diluted by a factor of 426 at 5 m from the discharge centre and by a factor of 1065 at 50 m from the discharge centre (CSA, 1993). The current speed at the time of measurement was 15 cm s^{-1} with little vertical stratification of the water column. The OOC model, but not the CORMIX model, accurately predicted the dilutions measured in the field. Produced waters of the Gulf of Mexico contain high concentrations of dissolved barium. It is probable that the radium in the produced water co-precipitated rapidly with barium sulfate in the sulfate-rich receiving waters.

The comparison of field measurements of hydrocarbons and various other organic components from both fixed stations sampling and continuous towed fluorometer with modeled data showed that measured dilutions were generally much higher than predicted (Murray-Smith et al., 1996). The measured dilutions with distance for alkanes and methylnapthalenes at 100-1000 m were extremely low. The measured dilution factors ranging from 5000-50,000 were much greater than predicted. The study also found that the measured concentrations of other organics such as phenol and methylphenol in the water column were below detection limits. Similar results were also reported for the analysis of five heavy metals in produced water samples collected from the Java Sea, where a high dilution ratio was observed as predicted in the models (Smith et al., 1996).

Terrens and Tait (1996) measured concentrations of BTEX and several PAHs in ambient seawater 20 m from an 11,000 m^3 d^{-1} produced water discharge from a platform in the Bass Strait, southeastern Australia (Table 3-8). They observed an inverse relationship between molecular weight (and volatility) and the dilution of individual aromatic hydrocarbons. The produced water discharge contained an average BTEX concentration of 6,410 μg L^{-1}, although the average concentration at 20 m from the discharge centre was 0.43 μg L^{-1}, marking a dilution of 14,900 fold. The PAH concentrations were diluted by 11,000 fold for naphthalene and 2,000 fold for pyrene. Concentrations of higher molecular weight PAHs at the sample location were below the detection limit of 0.0002 μg L^{-1}. The inverse relationship between molecular weight of the aromatic hydrocarbons and their rates of dilution probably was due in large part to the high temperature of 95 ºC of the discharged produced water, which may have favoured evaporation of the lighter aromatic hydrocarbons.

Table 3-8. Concentrations (μg L^{-1}) of four PAHs in produced water discharge, seawater collected 20 m down-current of the discharge centre, and its dilution from the Kingfish B Platform in the Bass Strait, southeast Australia (Terrens and Tait, 1996).

PAH	Produced Water (μg L^{-1})	Down-current (μg L^{-1})	Dilution
Fluoranthene	0.8	0.0002	4,000
Naphthalene	440	0.04	11,000
Phenanthrene	18	0.003	6,000
Toluene	3,000	0.18	16,700

Field measurements are important for both understanding of the fate of produced water and for model validation. Traditionally, this was achieved by either collecting water samples at pre-determined stations or by continuous towing of a fluorometer (Smith et al., 1994; Murray-Smith et al., 1996; Smith et al., 1996; Terrens and Tait, 1996; Smith et al., 2004). Traditional ship-based sampling methods are often expensive and time consuming and, as a result, only limited information can be collected. Increased water depth also increases the level of sampling error. Recently, new and innovative means of conducting field measurements using Autonomous Underwater Vehicles (AUV) have been proposed and may be used in the future study of produced water fate and to collect data to validate mathematical fate and transport models (Niu et al., 2007; Niu et al., 2009d).

To date, the majority of plume dispersion and chemical fate and transport models that have been developed focus on the process of dispersion and treat produced water as a single conservative contaminant. Only a few models have attempted to include other transformation processes, such as biodegradation, evaporation, and adsorption. Among these models, the most comprehensive appears to be the DREAM model which is capable of handling a multitude of complex processes and data, including discharge volumes, physical, chemical, and biological fates of discharged substances, and biological uptake and effects (Reed et al., 2001). Capable of predicting the fate of individual contaminants associated with produced water, the model is currently used extensively by North Sea operators to achieve the regional regulatory goal of 'zero harmful effect discharges'. The model can also be used to study the environmental effects of produced water using two approaches: the environmental impacts factor and a body burden-related risk assessment model.

3.4.4 Impacts on Marine Environment

Based on the concentrations of toxic chemicals found in most produced waters and their predicted dispersion rates, it is envisioned that there would be only limited potential for acute toxicity beyond the immediate vicinity of rig sites in Atlantic Canada. This is attributed to the sensitivity of the biotests, primarily regulatory acute toxicity assays, and the rapid dispersion of the process stream (Lee et al., 2005b). Holdway (2002), however, noted that to fully assess the potential impact of produced water discharges, the chronic impacts associated with long-term exposures must be quantified. Continual long-term chronic exposure may cause sub-lethal changes in organisms including decreased community and genetic diversity, lower reproductive success, decreased growth and fecundity, respiratory problems, behavioural and physiological disorders, decreased developmental success, and endocrine disruption. Chronic toxicity studies are ongoing by DFO to support the development of cost-effective and sensitive monitoring protocols for regulatory use.

3.4.4.1 Impacts on Pelagic Organisms

Biological effects in water column biological communities near open-ocean produced water discharges are expected to be localized because of the rapid dilution and dispersion rates of most produced water discharges into the ocean. Some produced waters, however, contain chemicals that are toxic to sensitive marine species, even at low concentrations. In particular, for produced water discharges in areas of limited water turbulence and low current speeds, concentrations of chemicals may remain high for enough time to cause ecological harm (Neff, 2002). The chemicals of greatest environmental concern in produced water, because of their potential for bioaccumulation and toxicity, are metals and hydrocarbons. Highly-alkylated phenols (i.e. octyl- and nonyl-phenols), though well-known to be endocrine disruptors, have not been detected in produced water at high enough concentrations to cause harm to water column animals following initial dilution. Nutrients, such as nitrate, phosphate, ammonia, and organic acids, may stimulate microbial and phytoplankton growth in the receiving waters (Rivkin et al., 2000; Khelifa et al., 2003). Some production treatment chemicals are toxic and, if they are discharged at high enough concentrations in produced water, may cause localized harm. Salts, such as sodium, potassium, and chloride, are not of concern in produced water discharges to the ocean, but they are of concern when the treated water is discharged to land or in fresh, surface waters or brackish waters.

3.4.4.2 Accumulation and Impacts in Sediments

If water depths are shallow, some metals and higher molecular weight aromatic and saturated hydrocarbons may accumulate in bottom sediments near produced water discharge centres and possibly harming bottom living biological communities (Neff et al., 1989b; Means et al., 1990; Rabalais et al., 1991). In well-mixed estuarine and offshore waters, elevated concentrations of saturated hydrocarbons and PAHs in surficial sediments may be observed out to a few hundred metres from a high-volume produced water discharge. The concentrations of PAHs in sediments near offshore produced water discharges are related to the volume and density of the produced water discharged, the PAH concentration in it, and the local water depth and mixing regime. Polycyclic aromatic hydrocarbons in sediments near offshore platforms may also come from drilling discharges, particularly if oil based drilling muds are used (Neff, 2005).

Barium, iron, and manganese are the metals most enriched in produced waters compared to their concentrations in natural seawater. A phase transition typically occurs following the release of produced water where the metals tend to precipitate rapidly when produced water is discharged to well-oxygenated surface waters high in sulfate. These particulate metals tend to settle slowly out of the water column and accumulate to slightly elevated concentrations in surficial sediments over a large area around the produced water discharge centre

(Neff, 2002; Lee et al., 2005b). In addition, the transport and concentration of inorganic constituents in produced water (e.g. metals) that reaches the surface microlayer may be promoted by the interaction between residual oil droplets and metal precipitates (Lee et al., 2005b). Toxicity assessment using the Microtox Test®, a regulatory bioassay protocol based on inhibition of a primary metabolic function of a bioluminescent bacterium, demonstrated that unfiltered samples containing metal precipitates generally had higher toxicity levels than filtered samples (Azetsu-Scott et al., 2007). Results from regulatory EEM programs generally indicate that natural dispersion processes control the concentrations of toxic metals in the water column and sediments, where they have been observed to be slightly above natural background concentrations.

3.4.4.3 Toxicity

Most treated produced water has a low to moderate toxicity. A typical distribution of produced water toxicities can be seen in the data of produced waters discharged to the Gulf of Mexico off the Louisiana coast (Table 3-9). A small number of produced waters are moderately toxic to mysids, a small shrimp-like crustacean, and sheepshead minnows, with acute and chronic toxicities less than 0.1 percent produced water (1000 mg L^{-1}). A few produced waters are largely nontoxic, as there is no evidence of acute and chronic effects in test waters containing less than 35-40% produced water. Most produced waters, however, have moderate toxicities with acute and chronic toxicities approximately 2-10% for mysids and 5- 20% for sheepshead minnows. Based on earlier toxicity studies of produced waters from the Gulf of Mexico, Neff (1987b) reported that nearly 52% of all median lethal concentrations (LC_{50}) were greater than 10% produced water, 37% were between 1-9.9%, and 11% were less than 1%. These toxicity threshold limits are consistent with those reported for Atlantic Canada.

Table 3-9. Toxicity of over 400 produced water (PW) samples from the Gulf of Mexico (offshore of Louisiana) on mysids (Mysidopsis bahia) and sheepshead minnows (Cyprinodon variegatus). Exposure concentrations are percent produced water (modified from Neff, 2002, p.30).

Toxicity Test	Number of Samples Tested	Concentration (% PW)	Standard Deviation
Mysidopsis bahia:			
Acute Toxicity (96 h LC50)	412	10.8	10.4
Chronic Survival (NOEC)	407	3.4	5.8
Chronic Growth (NOEC)	391	2.4	3.6
Chronic Fecundity (NOEC)	274	2.7	3.2
Cyprinodon variegates:			
Acute Toxicity (96 h LC50)	359	19.2	14.8
Chronic Survival (NOEC)	401	6.3	9.0
Chronic Growth (NOEC)	395	5.2	8.1

NOEC: No observed effects concentration.

Mixed-function oxidase enzyme activity was highly induced in the liver, gills, and heart of juvenile cod exposed to 5% produced water for 72 hours (Andrews et al., 2009). Histological changes were observed in the gills of fish exposed to relatively high levels of produced water. In studies with *Calanus finmarchicus,* a major prey species for fish in the Northwest Atlantic Ocean, no differences in mortality were found between control and experimental animals exposed to 5% produced water for 48 hours (Payne et al., 2001a). In a comprehensive study on the acute effects of produced water recovered from a Scotian Shelf offshore well on the early life stages of haddock, lobster, and sea scallop, in terms of survival, growth, and fertilization success, Querbach et al. (2005) noted that fed, stage I lobster larvae were the most sensitive with an observed LC_{50} of 0.9%. Feeding stage haddock larvae and scallop veligers were the least sensitive with LC_{50} of 20% and 21%, respectively. In terms of chronic responses, the average size of scallop veligers was significantly reduced after exposure to produced water concentrations greater than 10%.

There are poorly-characterized species differences in the toxicity of produced waters to marine organisms. When bioassays were performed with two or more marine taxa and the same sample of produced water, crustaceans were generally more sensitive than fish (Neff, 1987b; LDEQ, 1990; Jacobs and Marquenie, 1991; Terrens and Tait, 1993). Gamble et al. (1987) introduced produced water at a concentration equivalent to a 400-500 fold dilution of produced water (expected in 0.5-1.0 km from the Auk and Forties platforms in the North Sea) into 300 m^3 mesocosm tanks containing natural assemblages of phytoplankton, zooplankton, and larval fish. Bacterial biomass increased, although phytoplankton production and larval fish survival were unaffected in the produced water-dosed containers. Early life stages of copepods, however, were sensitive to the produced water and exhibited a high mortality. Decreases in zooplankton abundance resulted in an increase in the standing stock of phytoplankton and a reduction in the growth rates of fish larvae. In other mesocosm studies summarized by Stephenson et al. (1994), larval mollusks and polychaete worms were adversely affected by produced water exposure. The mesocosm studies demonstrate that low concentrations of produced water may have subtle effects on marine planktonic communities. It is noted, however, that mesocosm studies represent conservative, worst-case exposure scenarios because produced water chemicals in the mesocosm enclosures do not degrade and disappear as rapidly as they would in well-mixed ocean environments.

3.4.4.4 Bioaccumulation, Biomarkers, and Exposure

Bioaccumulation is the uptake and retention of a bioavailable chemical from any one of or all possible external sources (e.g. water, food, substrate, and air) (Neff, 2002). Marine animals near a produced water discharge may bioaccumulate metals, phenols, and hydrocarbons from the ambient water or from their food. Biomarkers are biochemical, physiological, or histological changes in an organism that result from exposure to specific chemicals in their water or food

(Forbes et al., 2006). Biomarkers typically are not direct indicators of harmful effects caused by exposure, but they can be used as early warnings of possible risk to an exposed organism, with the understanding that histopathological changes can be linked to harmful effects to a greater degree than for instance a slight biochemical or immune response. The most useful biomarkers respond to a single or small group of chemical contaminants and, so, can be used as evidence of exposure to a particular class of chemicals. For example, any of several measures of the induction (i.e. increase in activity) of the enzyme system, cytochrome P450 mixed-function oxygenase, can be used as evidence of exposure to PAHs, polychlorinated biphenyls (PCBs), and any of several other chlorinated hydrocarbon pesticides.

Produced water can be a source of PAHs in waters and sediments around oil development sites. The effect of PAHs has been determined in numerous studies conducted in the laboratory and field studies using endpoints based on biochemical, histopathological, immunological, genetic, reproductive, and developmental parameters (Payne et al., 2003). Concentrations of PAH were measured in the water column and in blue mussels (*Mytilus edulis*) deployed at different distances from production platforms in the Norwegian sector of the North Sea (Johnsen et al., 1998; Røe Utvik et al,. 1999; Durell et al., 2006 ; Neff et al., 2006). Direct measurements of PAH in the water gave inconsistent results, because concentrations were too low and variable. The mussels, however, did bioaccumulate PAHs from the water, even though concentrations decreased with distance down-current from the platforms.

Polycyclic aromatic hydrocarbon residues in mussel tissues were used to estimate PAH concentrations in surface waters (Neff and Burns, 1996). Surface water total PAH concentrations ranged from 0.025-0.35 µg L^{-1} at 1 km from the platform discharge centre, reaching background levels of 0.004-0.008 µg L^{-1} at 5-10 km from the discharge centre. This was equivalent to approximately a 100,000 fold dilution of the PAH concentration. Dilution modeling exhibited that most of the produced water plume was restricted to the upper 15-20 m of the water column and that dilution was very rapid. The DREAM model predicted that the concentrations of PAH and other chemicals in the produced water plume exhibited wide cyclic concentration variations due to tidal and wind-driven current flows. Because of rapid dilution and fluctuating water-column concentrations, the model predicted that potentially toxic concentrations and contact times of PAH would not occur even in the near-field.

Børseth and Tollefsen (2004) monitored bioaccumulation and biomarker responses in mussels and Atlantic cod held in cages in the vicinity of the Troll B Platform, Norway. Cages were deployed for six weeks both inside (500 and 1000 m from the discharge centre) and outside the zone of expected influence of the produced water plume. The investigators found no significant difference in levels of plasma vitellogenin, an indicator of exposure to endocrine-disrupting chemicals, in male cod from exposed and control sites. No significant differences were detected in ethoxyresorufin-*o*-deethylase (EROD) activity, a biomarker of exposure to chemicals, including PAHs, which induced the cytochrome P450 mixed function oxygenase enzyme system, in livers of fish of exposed and control sites. This indicated little or no exposure to PAHs. Levels of PAH metabolites in cod bile were also low, confirming the low level exposure to PAHs. Furthermore, concentrations of naphthalene metabolites in cod bile decreased with distance from the platform, indicating that the low-level exposure to PAHs was likely the result of the produced water discharge. Other biomarkers showed little or no evidence that the cod were affected by exposure to chemicals from the produced water plume.

Børseth and Tollefsen (2004) found that concentrations of metals and PAHs in soft tissues of caged mussels correlated well with distance from the produced water discharge centre, with the highest body burdens in mussels observed closest to the platform. The PAH assemblage in mussel tissues was dominated by alkyl homologues of naphthalene, phenanthrene, and dibenzothiophene, which suggests exposure to PAHs from the produced water discharge. Biomarker responses in the mussels provided equivocal evidence of exposure to produced water chemicals. The authors concluded that mussels and cod deployed near a produced water discharge likely were exposed to low concentrations of produced water chemicals, below levels that might represent a health risk to water-column organisms.

All three developers on the Grand Banks (i.e. Petro-Canada, Husky, and Hibernia) are carrying out health effect studies, such as condition index, gross pathology, liver and gill histopathology, haematology, and induction of MFO enzymes, on American plaice (*Hippoclossoides platessoides*) collected in the vicinity of their development sites. American plaice, an important commercial fish species on the Grand Banks, is presently undergoing recovery and was identified as the species of primary interest for studies on fish health early on in the development of EEM programs (DeBlois et al., 2005; Husky Energy, 2005). American plaice undergoes feeding related movements into the water column in addition to its tendency for sediment contact (Beamish, 1966; Pitt, 1967). Among other favourable characteristics, this enhances its potential for 'integrating' contaminant exposure via the water column through both feeding and water contact, as well as through interaction with sediments.

Studies carried out on American plaice at the Terra-Nova development site for a number of years, both before and after release of produced water, have noted that the over all health of American plaice collected in the vicinity of the development site is similar to the health of American plaice collected at distal control sites (Mathieu et al., 2005; Mathieu et al., 2011). Although studies have been of shorter duration, similar results have been observed at the Husky and Hibernia development sites through their EEM programs. Elevated MFO enzyme levels, however, have been noted in fish larvae collected downstream of the Hibernia field (Payne et al., 2003). Induction may only be occurring near the rig site with the induced larvae being transported downstream with currents. Nevertheless, the observation on MFO induction in fish larvae is of interest since it has been correlated with larval mortality (Carls et al., 2005).

Sturve et al. (2006) exposed juvenile Atlantic cod to North Sea oil, nonylphenol, and a combination of the North Sea oil and an alkylphenol mixture in a flow-through system. A suite of hepatic biomarkers were monitored. While exposure to North Sea oil resulted in strong induction of CYP1A protein levels and EROD activities, the corresponding exposure to nonylphenol resulted in decreased CYP1A levels and EROD activities. As a result, nonylphenol appeared to down-regulate CYP1A expression in Atlantic cod. Meier et al. (2007) described the effects of alkylphenols (APs) on the reproductive potential of first-time spawning Atlantic cod. In laboratory studies, cod were fed with feed paste containing a mixture of four reference alkylphenols at a range of concentrations for 1 or 5 weeks. Results demonstrated that AP-exposed female fish had impaired oocyte development, reduced estrogen levels, and a delayed estimated time of spawning of 17-28 days. Male AP-exposed fish had impaired testicular development, with an increase in the amount of spermatogonia and reduction in the amount of spermatozoa present. From the results of the laboratory studies, the Meier et al. (2007) concluded that APs associated with produced water discharge may have a negative impact on the overall reproductive fitness of cod populations. As toxic effects are directly linked to dosage and exposure time, the ecological significance of laboratory biomarker studies remains uncertain, since factors such as fish movement and contaminant uptake and elimination are not considered, as well, alkylphenol concentrations in samples of sea water near platforms are typically below the limits of detection.

Andrews et al. (2009) recently conducted chronic toxicity studies on cunners and juvenile cod exposed to produced water from the Hibernia field on the Grand Banks. The health effect indicators studied included fish and organ condition, visible skin and organ lesions, levels of MFO enzymes, haematology (differential white blood cell counts), a variety of histological indices in liver and gills, and vitellogenin (a biomarker for 'oestrogenic' endocrine disruption). The fish were dosed every 2-3 days for 6-8 hours with 1-2 ppt of produced water. Exposures were carried out for a 3 month period. No changes in various indices were noted with the exception of red and white pulp in the spleen, which is associated with red and white blood cells respectively. Lymphocyte levels were also depressed in the blood (Payne et al., 2005). Similar results were obtained with juvenile codfish with the exception of haematological effects which, unlike cunner, were not observed in cod. Elevated levels of MFO and vitellogenin, however, were recorded in the exposed fish (Payne et al., 2005). A chronic toxicity study was carried out with cunner exposed to barite, which can form from the interaction of barium in produced water with seawater. Barite is also a major constituent in drilling muds. Cunners were exposed on a weekly basis for 40 weeks to 200 g clouds of insoluble barite in a 1800 L tank. Barite, which accumulated on the bottom of the tank, was not removed. Fish survival and indices of fish health, as assessed by fish and organ condition and detailed histological studies on liver, gill and kidney tissue, did not differ between the control and experimental groups. Elevated levels of MFO enzyme activity, however, was found in the exposed fish (Andrews et al., 2007).

As part of the Biological Effects of Contaminants in Pelagic Ecosystems (BECPELAG) Program, bioaccumulation and several biomarkers were measured in wild and caged marine animals along a transect away from the Statfjord Platform in the North Sea (Hylland et al., 2006). Produced water discharge was 74,100 $m^3 d^{-1}$ from three platforms in the Statfjord field (Durell et al., 2006), which is among the highest discharge rates of any offshore field in the world (Figure 3-10). Førlin and Hylland (2006) measured EROD activity and bile metabolites in juvenile cod caged at several distances down-current from one of the discharges. There were no significant trends in EROD activity in male and female cod with distance from the discharge, though there was a trend for EROD activity in female cod to increase with distance from the discharge (Figure 3-11a). Concentrations of alkyl naphthalene metabolites, abundant in produced water, in fish bile were highest in cod near the platform and decreased with distance from the platform (Figure 3-11b). There were no distance trends in concentrations of other PAH metabolites in the cod bile. The authors concluded that the cod were exposed to low levels of PAHs from the produced water discharges, although exposure levels were well below those that would pose a health risk to fish living proximal to the platforms. In addition to the Førlin and Hylland (2006) study, a number of other studies have noted induction in wild fish and caged fish: North Sea (e.g. Davies et al., 1984b; Stagg et al., 1995; Abrahamson et al., 2008) and coastal Australia (e.g. King et al., 2005; Zhu et al., 2008). Elevated levels of MFO enzymes have been observed in fish larvae collected around some platforms in the North Sea (Stagg and MacIntosh, 1996). A slight elevation of MFO enzymes in American Plaice has been observed on occasion around some sites on the Grand Banks (Mathieu et al., 2011).

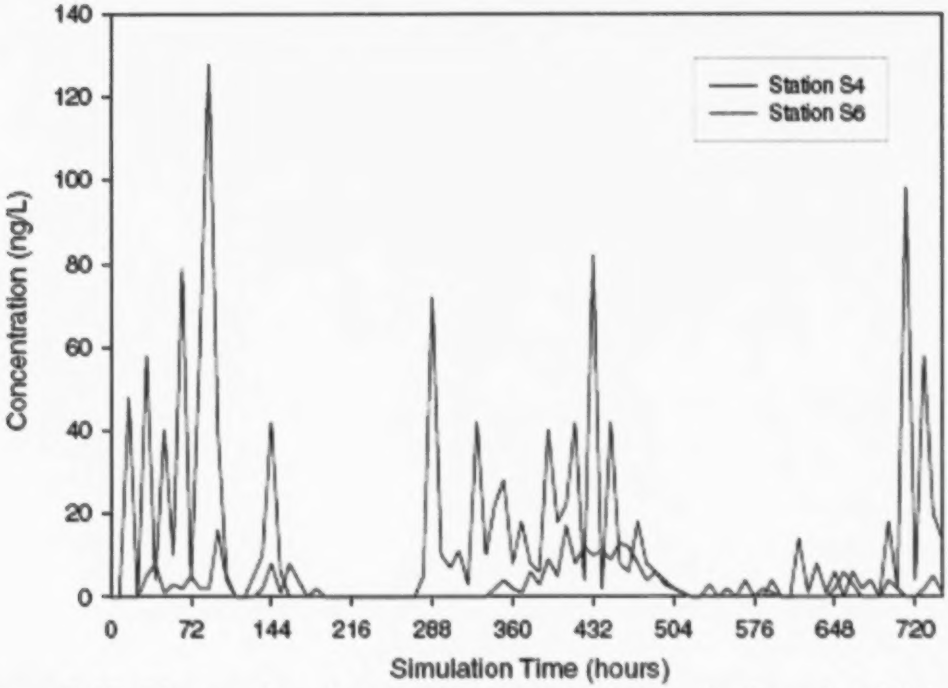


Figure 3-10. Time series of modeled total PAH concentrations (naphthalenes through 5-ring PAH) at Station S4 and Station S6 down current from a produced water discharge centre, Ekofisk Field (Durell et al., 2006).

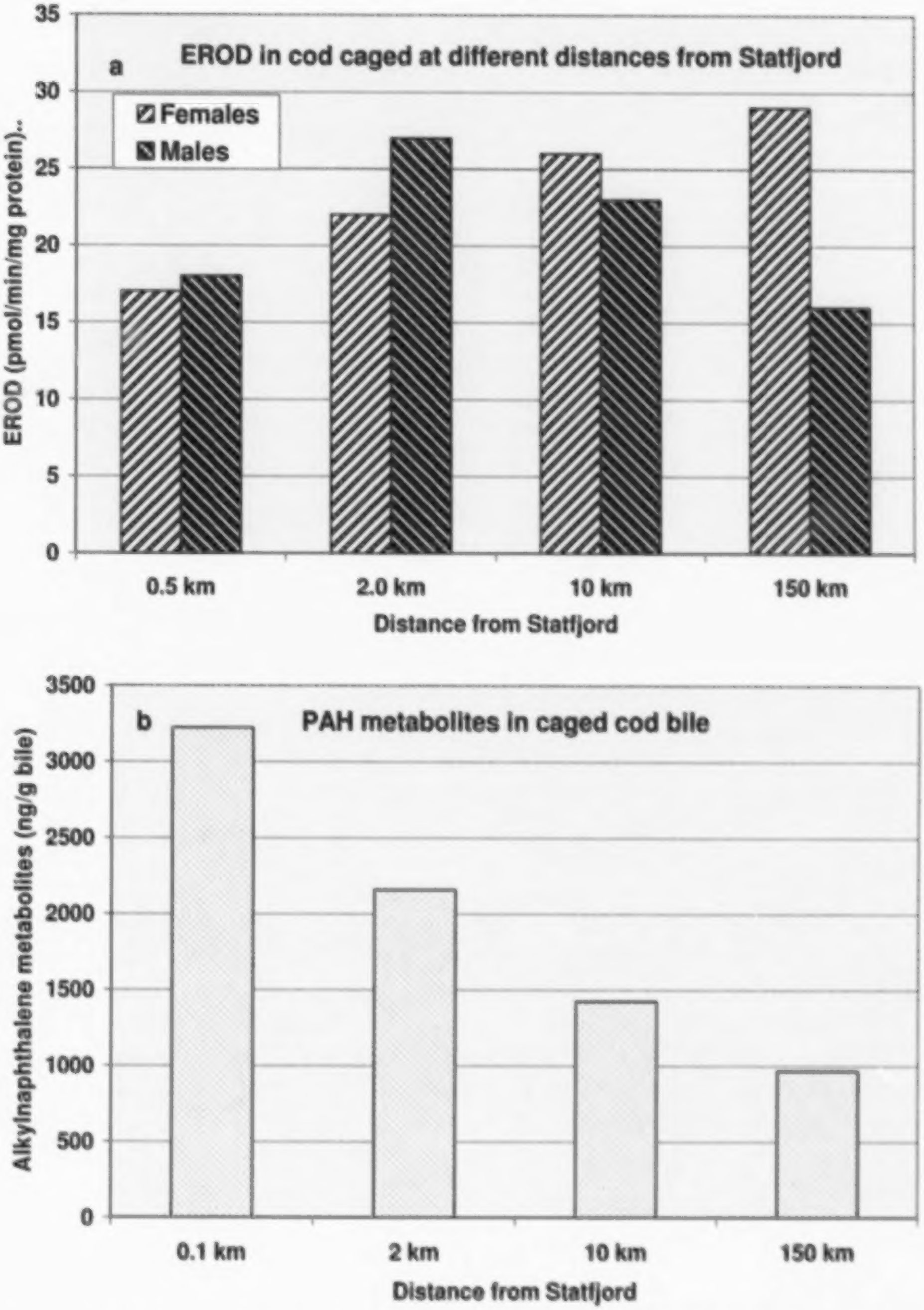


Figure 3-11. EROD activity (a) and PAH metabolites (b) in caged cod at different distances from the Statfjord Oil Field (Førlin and Hylland, 2006).

A study by Hamoutene et al. (2011) investigated the effects of produced water cod immunity, feeding, and general metabolism by exposing fish to diluted produced water at concentrations of 0, 100, and 200 mg L^{-1} for 76 days. No significant differences were observed in weight gain or food intake. Similarly, serum metabolites, whole blood fatty acid percentages, and mRNA expression of a brain appetite-regulating factor (i.e. cocaine and amphetamine regulated transcript) remained unchanged between groups. Other than an irritant-induced alteration in gill cells found in treated cod, resting immunity and stress response were not affected by produced water. Catalase and lactate dehydrogenase changes in activities were recorded in livers but not in gills, suggesting an effect on oxidative metabolism subsequent to hepatic detoxification processes. To evaluate potential effects of produced water discharges on cod immunity, fish from the three groups were challenged by injection of *Aeromonas salmonicida* lipopolysaccharides (LPS) at the end of exposure. The LPS injection affected respiratory burst (RB) activity of head-kidney cells and circulating white blood cell ratios, which increased serum cortisol in all groups. The most pronounced changes were seen in the group exposed to the highest dose of produced water of 200 mg L^{-1}.

Pérez-Casanova et al. (2010) investigated the effects of chronic exposure to produced water on some aspects of juvenile Atlantic cod immunity, stress response, and growth by intermittently exposing fish to 0, 100 or 200 mg L^{-1} of produced water for 22 weeks. The RB of circulating leukocytes was significantly elevated in the 100 mg L^{-1} treatment, while the RB of head-kidney leukocytes was significantly decreased in both the 100 and 200 mg L^{-1} treatments. Significant up-regulation of the mRNA expression of β-2-microglobulin, immunoglobulin-M light chain, and interleukins-1-β and -8 was observed in the 200 mg L^{-1} treatment and the down-regulation of interferon stimulated gene 15 was obvious for both the 100 and 200 mg L^{-1} treatments. No significant effects of produced water were observed on growth, hepatosomatic index, condition factor, or plasma cortisol. With most immune parameters being stimulated, the results support the need for further studies to determine if chronic exposure to environmentally-relevant concentrations of produced water could cause modulations of the immune system of juvenile Atlantic cod, which results in an energetic cost to the fish that may be detrimental. In terms of benthic organisms, a preliminary study was carried out with scallops in which they were exposed to 2 ppt of produced water from the Hibernia field every 2 days over a period of approximately four months. No differences in mortality or condition indices were observed between the control and exposed treatment groups. A similar long-term study using mussels also found no effect of produced water on mortality (pers comm. J. Payne, DFO).

3.4.5 Ecological Risk of Produced Water Discharges

The DREAM model has been adopted for determination of contaminant effects of produced water discharges and the level of risk it may impose on the marine ecosystem. Risk assessments can be conducted under the DREAM model using two approaches: 1) a body burden-related risk assessment model, and 2) the determination of an environmental impact factor. The first case is based on the ratio of a predicted environmental concentration (PEC) to a predicted no-effect concentration (PNEC), known as the PEC/PNEC ratio (Karman and Reerink, 1998). This can be followed up with the calculation of an environmental impact factor (EIF), which can be used for produced water impact reduction, management, and regulation (Johnsen et al., 2000).

The Norwegian oil and gas industry advocates ecological risk assessment as the basis for managing produced water discharges to the North Sea. Neff et al. (2006) compared estimates of ecological risks of PAHs in produced water to water-column communities, based on data of hydrocarbon residues in soft tissues of blue mussels deployed for a month near offshore platforms and based on predictions of DREAM. The study was performed near produced water discharges of the Tampen and Ekofisk Regions, Norwegian Sector of the North Sea. Because PAHs are considered the most important contributors to the ecological hazard posed by produced water discharges, comparisons focused on this group of compounds. The mussel approach is based on PECs of individual PAHs, estimated from PAH residues in mussels following deployment for a month near several produced water discharges, as well as on PNECs based on the log of the geometric mean of the acute toxicity value for a PAH regressed against its octanol/water coefficient (K_{ow}). The octanol/water partition coefficient is the concentration of a chemical in octanol (an organic solvent that is used as a surrogate for natural organic matter) divided by its concentration in water. A substance with a high K_{ow} is of environmental concern because it is readily absorbed by sediment and the fatty tissue of living organisms.

In the DREAM method, PECs for three PAH fractions were estimated in the 3D area around the produced water discharge centre. Predicted no-effect concentrations for each fraction were based on the chronic toxicity of a representative PAH from each fraction divided by an application factor to account for uncertainty in the chronic value.

The mussel method gives much lower estimates of ecological risk than the DREAM method (Figure 3-12). The differences are caused by the much lower PNECs used in DREAM than derived from the regression model approach, as well as by the lower concentrations of aqueous PAHs predicted by DREAM than estimated from PAH residues in mussel tissues. The two methods, however, ranked stations at different distances from produced water discharges in the same order and both identified two- and three-ring PAHs as the main contributors to the ecological risk of produced water discharges (Neff et al., 2006). Neither method identified a significant ecological risk of PAHs in the upper water column of the oil fields. The DREAM model may produce an overly conservative estimate of ecological risk of produced water discharges to the North Sea, because of the extremely conservative PNEC values for the various PAH fractions.

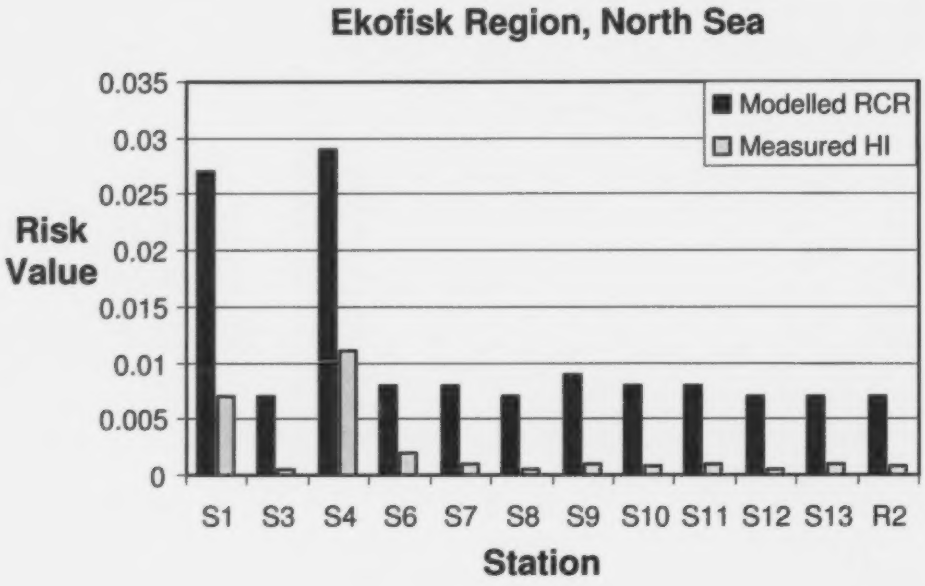


Figure 3-12. Risk characterization ratios (RCR) and hazard indices (HIs) for total PAHs. The RCR is the ratio of predicted environmental concentration (PEC) from DREAM to the predicted no effect concentration (PNEC) for select PAHs. The HI is the sum of ratios of measured PAH concentration in water to a modeled PNEC value. A risk value of 1 or higher indicates a possible risk to the health of marine organisms from the site (Neff et al., 2006).

Myhre et al. (2004) studied the reproductive effects of alkylphenols (APs) in produced waters on fish stocks of the North Sea using the DREAM model. The fish stock distributions (i.e. based on cod, pollock, and haddock data of the international bottom trawl surveys IBTS database) and a PNEC for APs of 4 ng L^{-1} were used as base data for the calculations of effects from the combined produced water discharges of three major Norwegian oil fields (Tampen, Ekofisk, and Sleipner). The total amount of >C4 APs discharged from all the oil production units was estimated to be 25.6 kg d^{-1}, dissolved in 364,300 m^3 d^{-1} produced water. The conclusion of the risk assessment was that "the overall results of the simulations with DREAM show that there is no significant risk potential" (Myhre et al., 2004). In the computer simulation, fish were represented mathematically as 'fish particles' which moved in and out of the effluent plume. In conclusion, there were no fish particles that accumulated APs above the critical body burden of 2 µg kg^{-1} in any of the simulations. The highest accumulated body burden in any of the fish particles was 0.09 µg kg^{-1}.

The accuracy of contaminant risk assessment models is dependent on the identification and quantification of the various chemicals that induce toxic effects. Unfortunately, the causative agents of toxicity in the most toxic produced waters are not known. Toxic responses may be linked to the extremely high total dissolved solids (salinity) concentrations, altered ratios of major seawater ions, and elevated concentrations of ammonia in some Gulf of Mexico produced waters (Moffitt et al., 1992). Salinity and ion ratios quickly return to those in sea water following ocean discharge of produced water, while ammonia evaporates or degrades rapidly. As such, the contaminants of concern found in produced water discharge streams rarely cause acute toxicity responses in the field.

Chemical kinetic reactions that occur following the release of produced water in an anoxic state into the open ocean have been found to alter the toxicity of produced water over time following its discharge (Lee et al., 2005b). The significance of this process is clearly illustrated in controlled dose-response experiments using natural microbial populations as the test organisms (Figure 3-13). A typical toxicity dose-response curve, with initial increase in productivity at low concentrations of produced water due to addition of nutrients followed by inhibition above a threshold value, is observed with fresh produced water. Following aeration for 44 hours, to simulate equilibration in the ocean following discharge, additions of the produced water over the same concentration gradient elicited a stimulatory response. The difference is attributed to the loss of low molecular weight hydrocarbons and precipitation of hydrolysis metals that may have sequestered toxic metals associated with sample aeration. The results imply that accurate comparisons of toxicological studies with similar end-points (e.g. LC_{50}) can not be made unless sample collection and handling protocols are standardized prior to toxicity testing.

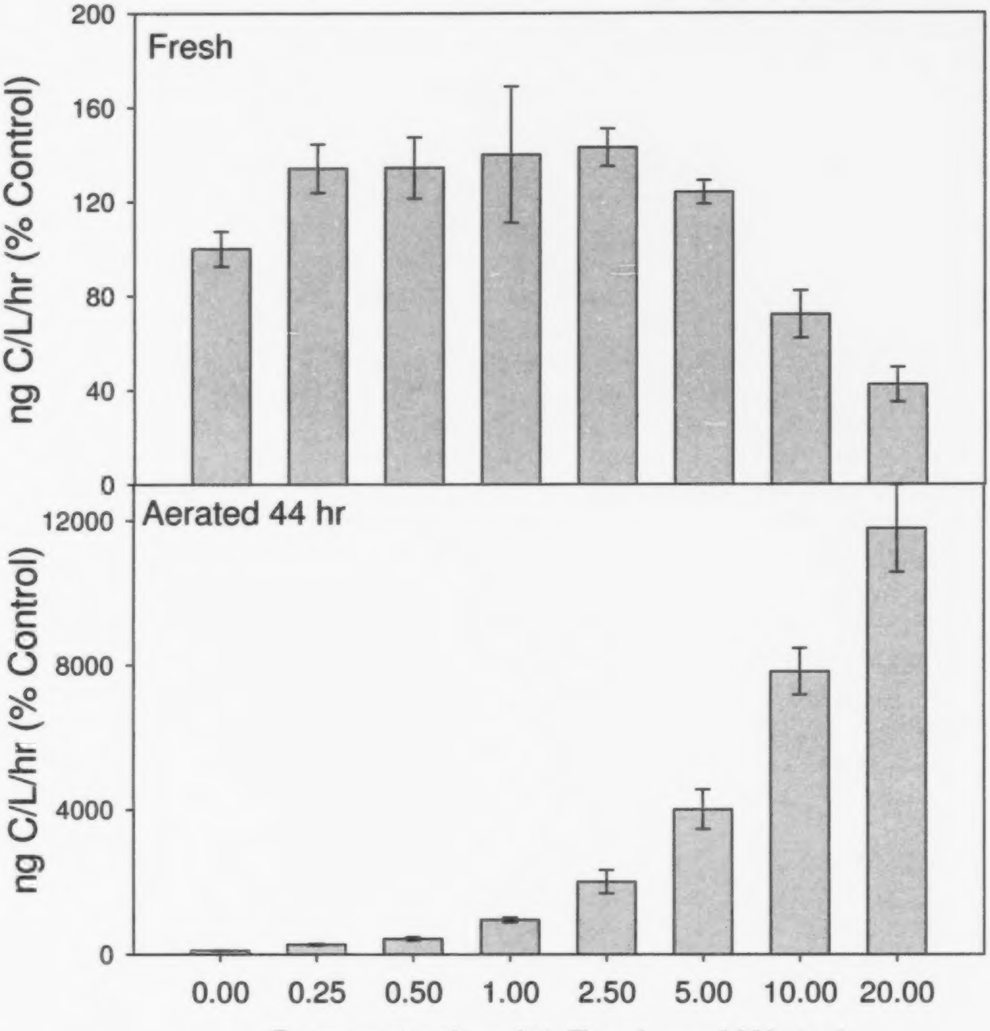


Figure 3-13. Dose-response of microbial carbon fixation rate (ng C L^{-1} h^{-1}) versus concentration of produced water. Produced water recovered from the Terra Nova FPSO on the Grand Banks was added to natural seawater and microbial productivity was measured by ^3H-thymidine uptake into DNA. Identical produced water samples were evaluated under identical conditions: immediately after collection (fresh) and after being aerated 44 hours.

In a modeling study to assess potential perturbations in food web structure and energy flow due to the discharge of produced water, Rivkin et al. (2000) predicted significant increases in productivity and sedimentation fluxes over large spatial domains, in response to produced water derived ammonia and dissolved organic carbon. At typical discharge rates, however, the effects of produced water discharges may be limited. Yeung et al. (2011) monitored changes in indigenous microbial community structures in response to produced water discharges from an offshore platform on the Grand Banks by denaturing gradient gel electrophoresis (DGGE). Results demonstrated that the production water did not have a detectable effect on microbial community structure in the surrounding water. Cluster analysis further showed a greater than 90% similarity for all near surface water (2 m) samples (at 2 m), 86% similarity for all the 50 m and near bottom samples, and 78% similarity for the whole water column from top to bottom across a 50 km range. The results were based on two consecutive yearly sampling events.

There were clear differences in the composition of the bacterial communities in the produced water compared to seawater near the production platform (approximately 50% similarity), indicating that the effect from produced water may be restricted to the region immediately adjacent to the platform. Members of the bacteria genus *Thermoanaerobacter* and of the Archaea genera *Thermococcus* and *Archaeoglobus* were identified as significant components of the produced water. These particular signature microorganisms could become useful markers to monitor the dispersion of produced water into the surrounding ocean. In general, bacteria have very short generation times and respond rapidly to environmental changes. Bacteria use in EEM programs has been recommended, since they are involved in primary processes including the production of carbon, nutrient cycling, and the biodegradation and/or biotransformation of contaminants (Lee and Tay, 1998; Wells et al., 1998). Studies by Anderson et al. (2000), with naturally occurring bacteria, indicated the potential for produced water to both inhibit (i.e. short term exposure at high concentrations) and enhance bacterial growth (i.e. lower concentrations over an extended period).

3.4.6. Further Research Needs

There have been many advances in scientific knowledge during the past decade regarding the composition, environmental fate, and biological effects of produced water discharges into the ocean. The general consensus of the 2007 International Produced Water Conference was that any effects of produced water on individual development sites in the open ocean are likely to be minor (Lee and Neff, 2009). The toxicity threshold limits for acute effects are not likely to occur beyond the immediate vicinity of the discharge pipe due to the effectiveness of natural dispersion processes driven by tides and currents. Unresolved questions, however, regarding aspects of produced water composition, its fate, and potential effect on the ecosystem remain. The effects of chronic toxicity may only become evident after monitoring several life stages or generations. It is important to acknowledge the consequences of long-term effects from offshore oil and gas facilities that may have a 15-20 year life-cycle. Furthermore, cumulative effects linked to future expansion of production operations must be considered.

It is evident that additional information is needed to improve the accuracy of existing risk assessment models for produced water discharge. Multidisciplinary scientific studies are needed under an ecosystem based management (EBM) approach to provide information on the environmental fates (i.e. dispersion, precipitation, and biological and abiotic transformations) and effects of chronic, low-level exposures to the different chemicals found in produced waters. Numerical models also need to be improved to better predict the fate and effects of chemical constituents found in produced water plumes that are rapidly dispersed. There is a need, however, to develop improved sample recovery and analytical techniques to support model validation needs. At present, many of the potential contaminants of concern in produced water cannot be detected in the open ocean environment with standard analytical protocols. The future development of high efficiency, cost-effective produced water treatment technologies is dependent on the identification and monitoring of the primary target constituents of environmental concern found in produced water (e.g. PAH, phenols, metals).

Interpretation of ecological risk from biological effect studies based on biomarker techniques remains a challenge. Biomarkers may be used to indicate that: 1) an organism has been exposed to a specific chemical or group of chemicals; 2) an organism is affected by a contaminant and responding to it; or 3) the organism has been damaged. According to Gray (2002) in an editorial comment entitled 'Perceived and Real Risks: Produced Water from Oil Extraction", it remains uncertain of the risk of produced water discharge to populations found in the field. Regarding discussion on the use of biomarkers and their 'translation' into population level effects, Payne et al. (1987) noted over 20 years ago that there is little or no conceptual basis for carrying out such 'translations.' It is now commonly accepted, however, that biomarkers are especially valuable for surveillance monitoring, diagnosing unanticipated health effects, and providing information on their geographical reach (Payne, 2007). As such, they are a valuable tool for the risk-management toolbox vis-à-vis scoping potential areas of concern or the dimension of the problem and assessing impacts on fish. It is also important to note that all bioindicators can not be treated equally in carrying out risk analysis. For instance, a variety of histopathological lesions appearing in the liver of fish would not be afforded the same adverse health status risk factor, as a small change in a sensitive enzyme activity. Even a sensitive response such as MFO enzyme induction has now been associated with a variety of metabolic, cellular, organ, and developmental disturbances (Mathieu et al., 2011 and reference therein) and, as such is, more than an indicator of contaminant exposure.

For a comprehensive protection plan, there is a need to support the development of improved monitoring protocols to provide early warning of any potential problems related to sediment and water quality (e.g. primary productivity), fish quality and fish health. Development of real-time monitoring systems (i.e. contaminant specific sensors and data-transfer technologies) may enhance our capacity to manage the ocean and its living resources. In consideration of natural perturbations currently occurring in the ocean (e.g. climate change) and the impacts potentially associated with other marine users (e.g. marine transport, fisheries, etc.), an ecosystem based, integrated management approach must be taken to fully evaluate the risks of produced water discharge into the ocean. In addition, alternative approaches to produced water management may also be considered. As an example, an alternative to ocean discharge of treated produced water is underground injection. The feasibility of this practice, however, at offshore installations is dependent on a number of site-specific factors, including access to a suitable disposal formation, chemical interactions that may result in precipitates that may plug the receiving formation, and cost. Last, the net environmental benefit of reinjection must be considered as, on the basis of energy requirements for injection, it is estimated that 2.6-4.3 g of carbon dioxide is emitted per liter of produced water reinjected into a sub-surface well (Shaw et al., 1999).

3.5 NATURAL SEEPAGE, SPILLS, BLOWOUTS, AND MALFUNCTIONS

3.5.1 Natural Seepage

A significant amount of crude oil is discharged each year from 'natural seeps'; areas from which liquid and gaseous hydrocarbons leak out of the ground into the marine environment. The observation of oil on the sea surface that has leaked from sub-marine oil reservoirs has been recorded throughout history. The locations of natural seeps have been used by geologists in their quest to locate unique geological structures and petroleum hydrocarbon reservoirs. In the North Atlantic Ocean, the occurrence of natural oil seeps has been well documented, from the Canadian Arctic (e.g. Grant et al., 1986) to the Gulf of Mexico (e.g. MacDonald, 1998). Levy and Lee (1988) reported the natural seepage of hydrocarbons in the Georges Bank region and postulated its potential ecological significance, as a carbon source, to the fisheries. The two most recent international reviews on the global input of oil into the sea (NRC, 2003b; GESAMP, 2007) still base their estimates of 4.2-14 million bbl annually of natural seepage on the values provided by Wilson et al. (1974) and Kvenvolden and Harbaugh (1983). Kvenvolden and Cooper (2003) stated "natural oil seeps may be the single most important source of oil that enters the ocean, exceeding each of the various sources of crude oil that enters the ocean through its exploitation by humankind." The most recent analysis of U.S. oil spillage conducted by the American Petroleum Institute reported that from 1998 to 2007 production-related petroleum spillage was less than 0.9% of the amount discharged from natural seeps.

3.5.2 Spills and Blowouts

In addition to the potential impacts of routine exploration and production activities, there are some events (e.g. oil spills and blowouts) that, although having a low probability of occurrence, have a much greater risk to the Georges Bank ecosystem. Spills, blowouts, and malfunctions are types of detrimental accidents to the environment that may occur during any offshore oil and gas exploration activities. As defined by the U.S. National Oceanic and Atmospheric Administration, a blowout occurs when operators of a drilling rig are unable to control the flow of oil, gas, or other fluids from the well and it is released into the underground formation, marine environment, and/or atmosphere. The U.S. Minerals Management Service also includes flow through a diverter or uncontrolled flow resulting from failure of surface equipment or procedures under its definition of a blowout (API, 2009). Blowouts can involve continuous discharge of petroleum gas into the atmosphere and/or crude oil into surrounding waters. Blowouts may not lead to a significant loss of hydrocarbons, as they often seal naturally and cease flowing within a matter of hours or days. In addition to the routine use of drilling fluids to control the underground pressures when drilling, offshore oil rigs have blowout prevention (BOP) systems to control the well when there is an influx of pressurized gas or oil during drilling. The BOP seals off the well and routes the wellbore fluids to specialized controlling equipment.

The rate of blowouts is very low in the oil exploration and development industry. For example, in the Gulf of Mexico from 1979 through to 1998 there were 19,821 wells drilled, with 118 wells resulting in uncontrolled flows or blowouts. This results in a 0.6% occurrence rate of blowouts for the region during this time. Furthermore, the majority of reported events involved the diversion of gas. Due to differences in defining a blowout, API (2009) states that there has only been 17 marine well blowouts in the U.S. since 1964, which resulted in a total of 249,000 bbl spilled. The largest of these blowouts occurred from the Alpha Well 21 off Santa Barbara, California, which spilled 100,000 bbl. In general, spill volumes have been small, with 50% of the well blowouts involving 400 bbl of oil or less.

During offshore petroleum exploration, there is usually no bulk storage or transfer of oil or gas, thus the risks and impacts of an oil spill are no more than that associated with marine shipping. With an increase in exploration and production operations, the incidence of marine oil spills would be expected to arise due to the escalation of marine traffic associated with construction and supply operations, including the potential use of sub-surface pipelines for oil and gas transportation. With advances in technology and improved operational safety measures, data from U.S. operations has indicated a decrease in combined spill volumes from offshore supply vessels, pipelines, and platforms, from 30,400 bbl y^{-1} (from 1969-1977) to 3,900 bbl y^{-1} (from 1998-2007), resulting in an 87% reduction in the average annual spill volume since the 1970s (API, 2009). Although the potential for harmful effects from an accidental petroleum discharge, such as a large oil spill, may be large, the probability of such an event occurring is low. Historical spill and blowout events support the prediction of probability of spill and blowout occurrence for new oil and gas drilling exploration and production activities (Table 3-10). Studies on marine oil pollution indicate that accidental petroleum discharges from platforms contribute 0.07% of the total petroleum input to the world's oceans (NRC, 2003b).

Table 3-10. Historical large oil spills in barrels (bbl) from offshore well blowouts (Oil Spill Intelligence Report database).

Offshore Region	Spill Size (bbl)	Year	Type of Activity
Mexico (Ixtoc 1)	3,000,000	1979	Exploratory Drilling
Dubai	2,000,000	1973	Development Drilling
Mexico	247,000	1986	Work over
Nigeria	200,000	1980	Development Drilling
North Sea/Norway	158,000	1977	Work over
Iran	100,000	1980	Development Drilling
U.S.A., Santa Barbara	77,000	1969	Production
Saudi Arabia	60,000	1980	Exploratory Drilling
Mexico	56,000	1987	Exploratory Drilling
U.S.A., S. Timbalier 26	53,000	1970	Wireline
U.S.A., Main Pass 41	30,000	1970	Production
U.S.A., Timbalier Bay/Greenhill	11,500	1992	Production
Trinidad Development	10,000	1973	Drilling

Worldwide, there have been five oil spills greater than 150,000 bbl in size in the history of offshore drilling, two of which occurred during development drilling and two of that occurred during production activities. The fifth, the Ixtoc 1 oil well blowout in the Bay of Campeche, Mexico, 1979, occurred during exploration drilling. The CNSOPB has predicted a 1-in-1800 chance per year of having any sort of deep water blowout off the continental shelf during exploratory drilling, with the probability of shallow water gas blowouts without a release of oil having a three to four times higher probability of occurrence (Hurley and Ellis, 2004). For operations in the offshore of Nova Scotia and Newfoundland and Labrador, one exploration gas well blowout, Uniake G-72, occurred off Sable Island in 1984 (Boudreau et al., 1999). Hurley and Ellis (2004) provided expected frequencies of exploration well blowouts based on the historical frequency of blowouts per wells drilled. They calculated that the predicted frequency of an extremely large blowout (>150,000 bbl) was one every 17,500 years. The frequency of a very large spill (>10,000 bbl) was one every 5800 years, and of a large spill (>1000 bbl) was one every 4400 years.

Oil spills other than from blowouts can occur during drilling and production activities due to an increased amount of marine traffic in the region. These include spills of diesel oil or lubricating oil on the platforms, spills from transfer operations, and spills from similar accidents involving the handling of oil that is needed to run operations. Based on statistical data from the offshore of Nova Scotia, presented by Hurley and Ellis (2004), the highest frequencies of oil spills are for the smaller, platform-based spills. Spills that are less than one barrel in size may occur once every two years. Oil spills during exploration, which are larger than one barrel but less than 50 bbl, have an approximately 1-in-10 or 1-in-20 chance of occurrence per year. From January, 1994, to August, 2002, five oil spills, including spills of synthetic oil-based drilling mud, occurred during exploration drilling on the Scotia Shelf that resulted from exploration and production activities (CNSOPB, 2010). In the Newfoundland and Labrador offshore petroleum region, in 2004, a 1000 bbl crude oil spill occurred from the Terra Nova FPSO due to equipment failure. While there was 296 spill events associated with exploration and production activities in the Newfoundland and Labrador region from 1997 and 2007, the total volume of hydrocarbons released was less than 1200 bbl (CNLOPB, 2010).

Concern has been raised in Atlantic Canada regarding the accuracy of predictions generated under the existing EIA process by Fraser and Ellis (2008), following the comparison of oil spill frequency predictions of small batch spills of hydrocarbons and synthetic hydrocarbons less than 50 bbl in volume to observed data for three projects. The authors noted that three projects exceeded their predicted frequencies, with the ratio for actual to predicted values greater than six for two of the projects. The implementation of a feed-back management process that responds to the results of EIA follow-up monitoring pursuant to the *Canadian Environmental Assessment Act* were recommended. In response, the CNSOPB concluded that their original EIA prediction for the Sable Offshore Energy Project was largely accurate, of 0.5 spills per year, when compared to the observed spill occurrence of 0.57 spills per year. For the other three sites in Atlantic Canada, the CNLOPB noted that the forecasts of spill occurrence for the Terra Nova and White Rose Projects were developed using the best data available at the time. In both cases the regulatory boards noted that they follow-up on all spills and that local spill occurrence information is used in the preparation of future EIAs.

Scientific studies on the transport and effects of petroleum hydrocarbons from oil spills and blowouts have been ongoing for decades. When crude oils and their refined products (including heavy fuel oils) are released to the marine environment, oil weathering processes occur. These processes include spreading, evaporation, dissolution, and dispersion of whole-oil droplets into the water column, water-in-oil emulsification, photooxidation, microbial degradation, uptake by organisms, adsorption onto suspended particulate material, sinking, and sedimentation. The rate and extent of oil weathering processes are dependent on many factors, including: oil types; mixing energy; temperature; and salinity of the marine environment. As a general rule, most fresh oils released to the sea surface spread in a few hours to reach an average thickness of 0.1 mm (ITOPF, 2005). The speed of oil spreading is determined by many physicochemical factors, for example, light crude oil spreads much faster than heavy fuel oil. Wind can significantly increase the spreading rate of oil. A rough sea with high mixing energy will significantly enhance the rate of spreading.

Volatile organic compounds in the spilled oil are evaporated and dissolved into the atmosphere and surrounding waters immediately after the oil is released into the environment. In wave tank studies, Payne et al. (1991) observed that all compounds with vapour pressures greater than n-C11 were lost, likely by evaporation, in 9 days under spring and summer conditions. The evaporation of oil under winter conditions is typically slower, but eventually the oil will evaporate to approximately the same degree as it would if spilled on the water in summer. Evaporation/dissolution loss can be a significant weathering process for many light crude oils, which can lead up to 50-60% loss of the spilled oil mass. Since evaporation is a surface phenomenon, the evaporation rate can be significantly influenced by the oil film thickness as a result of spreading. The rate of evaporation is also increased by strong winds, rough seas, and higher air temperature. Under turbulent hydrodynamic regimes (e.g. breaking wave conditions), a surface oil slick can be entrained as small oil droplets that are dissipated and diluted into the water column (Delvigne and Sweeney, 1988; Fraser and Wicks, 1995; Lee and Stoffyn-Egli, 2001; Lee et al., 2003). This is a natural process that is beneficial to oil spill clean up, because oil in the form of small droplets has a much higher surface-to-volume ratio than an oil slick and, as a result, undergoes biodegradation at a much higher rate. Furthermore, the formation of oil droplets enhances interaction with suspended particulate material and other natural attenuation processes.

Water-in-oil emulsion, formed by dispersion inversion or by water drop entrainment, is a competing process with dispersion of oil. Emulsification increases the volume of the contaminant oil and also decreases its rate of biodegradation. The formation of stable water-in-oil emulsions is an important factor influencing the success of various oil spill cleanup processes, including containment, in situ burning (due to lowered combustibility of the emulsions), and chemical dispersion (with increased difficulty). Rapid emulsion formation diminishes rates of evaporation and dissolution and, therefore, more toxic lower and intermediate molecular aromatic compounds will be retained in the residual oil for a longer period. The rate and extent of the formation of water-in-oil emulsions are dependent on oil properties, turbulence energy level, and natural environmental conditions. Photo-oxidation may be an important transformation processes of petroleum products released into the marine environment (Garrett et al., 1998; Dutta and Harayama, 2000; Prince et al., 2003a). Aromatic compounds are particularly sensitive to photo-oxidation, whereas saturated compounds are more resistant (Garrett et al., 1998); large size and increasing alkyl substitution increase the sensitivity of aromatic compounds to photo-oxidation. In contrast, larger and more substituted compounds are more resistant to biodegradation (Prince, 1993; Prince and Clark, 2004). It has been demonstrated that, while natural microbial populations in seawater partially biodegraded crude oil when sufficient nutrients were supplied, pre-treatment with photo-oxidation increased the amount of crude-oil components susceptible to biodegradation. This lead to significantly increased biodegradation of crude oil

(Dutta and Harayama, 2000). The photo-oxidation of petroleum products may increase toxicity (Shemer and Linden, 2007).

Biodegradation by microbial communities is the major process controlling the 'weathering' and eventual removal of oil entering the marine environment (Leahy and Colwell, 1990; Atlas and Bartha, 1992; Atlas, 1995). A large number of hydrocarbon degrading microorganisms have been isolated from a variety of marine environments (ZoBell, 1973; Atlas, 1984; Leahy and Colwell, 1990). Recently, Prince (2010) published a list of 181 genera of bacteria, 163 genera of filamentous fungi and yeast, and 22 genera of algae that are able to degrade hydrocarbons by growing them as carbon source. This is not surprising considering that marine microorganisms have long been exposed to petroleum hydrocarbons from natural seepages. Most crude oils are buoyant. When low molecular weight components have been removed by weathering or following interaction with suspended particulate material, however, residual fractions may sink. The relative amounts entering the various environmental compartments and the behaviour of the residual hydrocarbons depends on the type of event (e.g. platform blowout, seafloor blowout, or sea surface oil spill), composition and physical and chemical properties of the source hydrocarbon released, and environmental (e.g. wind, temperature, and salinity) and oceanographic conditions (e.g. waves, tides, and currents).

Spills of production chemicals used to ensure safety and to maintain production operations, such as monoethylene glycol (MEG), lubricating oil, diesel fuel, and hydraulic oil may also be spilled into the marine environment during offshore petroleum activities. Monoethylene glycol is an industrial anti-freeze that is injected into natural gas pipelines to prevent the formation of hydrates, or 'ice plugs', which can cause blockages (CNSOPB, 2008). As it is classified to be a low toxicity substance, the discharge of MEG has been approved in various jurisdictions. In 2006, a cracked pipe at the Sable Offshore Energy Project resulted in over 150 m^3 of MEG being released to the marine environment. No measurable impact was identified (CNSOPB, 2008).

3.5.3 Oil Spill Modeling

A large number of oil spill models, which cover a range of capabilities from simple trajectory modeling to three-dimensional trajectory and fate modeling, are used globally. Reviews of some of the most widely used models have been reported by Huang (1983), Spaulding (1988), Fingas (1995), ASCE Task (1996), and Reed et al. (1999). Advances in oil spill models have improved the ability to predict oil spill trajectory and impacts in the event of an accidental release of petroleum hydrocarbons in the marine environment. The application of predictive numerical models can be used to support risk assessment studies and to provide critical guidance for clean-up operations.

Oil spill trajectory modelling for summer conditions on the Northeast Peak of Georges Bank suggest that oil would travel in one of two principal directions. If winds are light than trajectories would likely be influenced by the residual current and slicks would generally move to the south and southeast. In contrast, under storm conditions, surface water movement would be driven by the winds and, as such, oil would move in the direction of the prevailing wind. The distance between the Georges Bank moratorium area and the Canadian shoreline, as well as the residual current, greatly reduce the probability of an oil slick encountering the shorelines of Atlantic Canada. It would be expected that a large portion of the crude oil in a slick would evaporate and disperse during transit, thus, the probability of shoreline fouling is considered to be low.

3.5.3.1 Fate and Transport Models

The accuracy of oil spill fate and transport models is continuously being improved. For example, while historical oil spill models have focused on surface trajectory and weathering, recent research has begun to evaluate the fate and impacts of spills that are largely entrained in the water column, as a result of high mixing energy due to the application of a dispersant (French-McCay and Payne, 2001; Reed et al., 2004; Nazir et al., 2008). To provide support for spill response and evaluation of habitat damage, Nazir et al. (2008) studied the fate of spilled oil in the water column and sediments using a Fugacity-based multimedia model to determine the extent of the area of impact and to define the size of the water and sediment compartments. They found that the water compartment exhibits a rapid decrease of oil concentration after input of to the sea is stopped, but that the sediment is slower to respond. Varlamov et al. (1999) simulated the movement of spilled oil, after an incident involving the Russian tanker *Nakhodka* in the Sea of Japan, using a particle-based oil spill model coupled with a regional ocean circulation model. The simulation demonstrated that 91.5% of the simulated oil volume and 62% of the modeled oil droplets were found in the upper 30 m layer of the water column. The study also found that the estimations of volume of oil redistributed both at the sea surface and in deep water is sensitive to the parameters used for weathering processes and the size distribution of the initial oil droplets.

French-McCay and Payne (2001) have modeled fate of spilled oil, specifically focusing on water column concentrations, resulting from oil spills with and without the application of oil-spill dispersant. For a hypothetical spill of 1500 t of Louisiana light crude on the water surface 25 km from the entrance of Galveston Bay, the results demonstrated that the application of dispersant at 2-3 hours after the spill greatly increased the percentage of the aromatics that dissolved into the water. It was also found that increasing the amount of dispersant and applying it sooner reduced the surface area of the shoreline that is ultimately oiled. Much of the simulations of oil spills have been conducted on large scales and the effects of waves have been accounted for using empirical formulations (Lehr, 2001). Since waves play an important role in the dispersion of oil slicks in the water column, Boufadel et al. (2007) simulated the oil droplet transport associated with regular waves (waves of constant frequency and height). It was found that Stokes' drift was the major mechanism for horizontal transport. The light oil droplets were found to propagate faster, but spread less, than heavier oils. Tkalich and Chan (2002) developed a kinetic model that considered the dominant forces affecting droplet formation and vertical distribution to describe the vertical mixing of oil droplets in breaking waves. They combined properties of oil, waves, and the water column into a single mixing factor to describe the droplet mass kinetics in the upper part of the water column. Because the wave dissipation rate that determines oil droplet size and affects the subsequent kinetics was not examined in the Tkalich and Chan (2002) approach, Chen et al. (2008) subsequently proposed a method that addressed turbulent dissipation.

Traditional stochastic oil spill models have focused on the production of statistics for oil on the sea surface and along shorelines. Environmental risk assessment models, therefore, have tended to neglect potential risks to organisms in the water column and sediments. A stochastic model has been described by Skognes and Johansen (2004), with modules for statistical analysis of oil drift, spreading, and weathering with respect to sea surface impacts and eventual shoreline impacts, as well as with respect to subsurface oil concentration. A model application for a spill off the coast of Norway demonstrated that oil contamination probabilities are higher for subsurface than for surface in areas surrounding the spill site. The simulation indicated that the average total subsurface hydrocarbon concentration in the impacted area ranged from 0.001-10 ppb.

3.5.3.2 Biological Effect and Risk Assessment Models

The vast majority of oil spill models developed to date are only focused on the prediction or hind-casting of the trajectory and fate of oil on the surface of water, in the water column, and sediments for the purpose of providing information for spill response, spill contingency planning, and evaluating a spill's mass balance. A few models, however, have been designed to evaluate the impacts of oil on aquatic organisms and habitats. Xiong et al. (2000) described an oil spill impact analysis software system that evaluated potential effects to exposed organisms based on results from a physico-chemical fate component, including the extent and characteristics of the surface slick, and dissolved and total concentrations of hydrocarbons in the water column. The model considered exposure to migratory adult fish populations, spawning planktonic organisms (eggs and larvae), and wildlife species (sea birds or marine mammals). Similar goals were also included in the OSCAR model described by Reed et al. (2000). Furthermore, Price et al. (2003) described an Oil Spill Risk Analysis model that estimated the probabilities of oil spill occurrence and contact to biological and economic resources using historical records of oil spills, winds, and ocean currents.

In terms of biological effects, the Spill Impact Model Application Package (SIMAP) proposed by French-McCay (2004a) integrated both physical fate and biological effect models. The biological exposure model of SIMAP estimates the area, volume, or portion of a stock or population affected by oil. The model calculates the losses resulting from acute exposure in terms of mortality and loss production because of direct exposure or loss of food resources from the food web. The application of SIMAP for the North Cape oil spill has been reported in French-McCay (2003; 2004a), with the predicted number of birds oiled and lobsters killed in agreement with field observations. In another application to the Exxon Valdez oil spill, SIMAP estimated that 3555 otters and 26 seals may be oiled. Further applications of SIMAP in the evaluation of environmental impacts are described by French-McCay (2004b) and French-McCay et al. (2002; 2003).

Although the formation of Oil-Mineral-Aggregates (OMA) enhances the dispersion of marine oil spills, the potential impacts of settled OMA to benthic organisms is not well known. A comprehensive numerical approach has been undertaken by Niu et al. (2010) to model the transport of OMA and assesses their potential risks. The predicted environmental concentrations of settled oil in OMA was calculated using a random walk particle tracking model and a benchmark concentration of individual hydrocarbon groups were computed based on a equilibrium partitioning approach. The risks in terms of a Hazard Quotient were then determined using a Monte-Carlo-Simulation method. The predicted results from a case study based on a spill of 1000 t of South Louisiana crude oil in the Gulf of St. Lawrence, with a water depth of 80 m, demonstrated that the possibility of OMA to cause sediment impacts depends on sediment type and physical environmental conditions.

3.5.4 Impacts on Marine Environment

If a blowout occurs, it usually results in the release of a mixture of gas, gas condensate, and/or oil. The three products behave differently in the water column and have different potential impacts. In the event of an accidental release of gas, it is anticipated that much of it would be rapidly dissipated into the atmosphere with the assistance of the wind. This is often true of the lighter components in condensate and crude oils. In the first hours and days after release, the lighter fractions evaporate. Gas condensate is a low density mixture of hydrocarbons present in natural gas that condense out of solution forming a liquid under standard temperature and pressure conditions. It is below the dew point of the gas. A large fraction of the hydrocarbon components in condensate may be soluble in water. Furthermore, many of the hydrocarbons found in gas condensate are highly toxic and, as such, the release of large quantities of condensate at the seafloor may cause local mortalities. It is expected that the impacts would be short-lived following the stoppage of flow, although depending on the duration, timing, and location there could be significant mortalities.

Two blow-outs occurred offshore Eastern Canada in 1984 near Sable Island; one at the West Venture N-91 site where no gas, oil, or condensate was released (Booth, 1990); and the other at the Uniacke G-72 well, which resulted in a spill of 240 m^3 of condensate. With respect to the latter, a total of seven oiled marine birds were observed during surveys over an extensive area around the well the day after capping – 11 days after the blow-out (Carter et al., 1985). Cod and haddock fillet and liver were analyzed for hydrocarbons by spectrofluorometry and by gas chromatography-mass spectrometry. Fluorescence emission, di-, tri-, and tetramethylbenzenes, naphthalene and its methyl- and dimethyl homologues, were used to detect contamination of gas condensate. Increased fluorescence and dimethyl benzenes were detected in the livers. It appeared that fish were exposed to the gas condensate, but the exposure was very low and did not affect the fish. The condensate was readily accumulated by juvenile Atlantic salmon in the laboratory. The excretion half-life was of the order of days (Zitko et al., 1984).

Oil associated with surface slicks may become mixed into the water column and/or become incorporated into sediments. The relative amounts entering the various environmental compartments, and their subsequent behaviour, depends on the type of event (i.e. platform blowout, seafloor blowout, or sea surface oil spill), composition and physical-chemical characteristics of the oil, atmospheric conditions (e.g. wind and temperature) and oceanographic conditions. An overview on the fate of oil spills and their impacts has been published by GESAMP (1993). This report included samples of case studies of blowouts and major oil spills under different environmental conditions, in order to summarize the general understanding of the behaviour, fate, and effects of oil released into the sea. It is expected that the bulk of any oil released in the marine environment would initially concentrate at the sea surface to form a slick, which would immediately be subjected to evaporation. Based on previous spills (e.g. Bunker C oil spill on Nantucket Shoals from the *Argo Merchant*) and model predictions (e.g. for Hibernia), it is expected that evaporation would remove 40-50% of the oil in the first 24 hours. The resultant oil would be broken up over a few days by processes such as dispersion, dissolution into the water column, photo-oxidation, and biodegradation. Under most conditions, surface slicks of unrefined oil should disappear after one to two weeks. The presence of an oil slick on the surface will have the most serious biological impacts on birds and marine mammals in the area. The amount of spilled oil that enters the water by dispersion and dissolution varies considerably with composition and environmental conditions, but is generally on the order of 5-15%. Dissolution is considerably less than dispersion because of the low solubility of most oil components. Oil in the water may have a higher potential toxicity than surface slicks due to the reduced potential for evaporation of the lighter toxic components.

Oil products enter the water column primarily through downward mixing. The depth to which oil penetrates depends on the wind, mixing, currents, and water column structure. High rates of vertical mixing may increase the amount of petroleum product entrained in the water column compared to other areas. Short-term concentrations that can be expected in the water column under blowout or spill conditions on Georges Bank are on the order of 10-200 ppb with an upper maximum of about 300 ppb (Boudreau et al., 1999). In stratified regions around the perimeter of the Bank, concentrations in deeper water should be substantially lower. Any high concentrations should be short-lived and return to background levels within a week or two (Boudreau et al., 1999).

Oil hydrocarbons concentrate in the surface microlayer (i.e. water-air interface) and at the water-seafloor boundary. Alterations in fish larvae mortality have been documented with increasing concentrations of oil contaminants in the surface microlayer (NERC, 1994). Sublethal effects, which are more difficult to measure, include changes in biochemical responses of enzyme systems in fish and invertebrates (Addison, 1992; Stebbing et al., 1992; ICES, 1994; GESAMP, 1995), increased frequency of histopathological changes and diseases in bottom fish and invertebrates (ICES, 1994), and degradation of ichthyoplankton communities in response to oil contaminants (Cameron et al., 1992; Shagaeva et al., 1993). Effects of large spill events are predicted to be greater in coastal areas and enclosed seas compared to open ocean pelagic areas (Patin, 1999). Oil concentrations on the order of 100 ppb have been demonstrated to cause both lethal and sublethal effects on planktonic organisms. Despite many studies, it is difficult to detect whether major spills or chronic oil input have any irreversible impacts on the marine planktonic communities. Ecosystem level impacts are often low since, 1) the volume of water contaminated with high oil concentrations is often limited in both space and time because of rapid dispersion and weathering; 2) planktonic organisms generally have rapid rates of regeneration on the order of days to months and can therefore quickly compensate for any loss; and 3) replacement phytoplankton and zooplankton can be readily mixed in from surrounding waters. In addition, natural bacteria have the capacity to metabolize a large fraction of the components in condensates and crude oil (Swannell et al., 1996; Lee, 2000). For example, Braddock et al. (1995) noted increased abundance of hydrocarbon-degrading microorganisms and the restructuring of microbial communities in bottom sediments following large spill events (e.g. Exxon Valdez).

Since spawning events of fish and invertebrates are generally restricted in time and place, there can be impacts on the year class recruitment if an oil spill coincides with such a spawning event. Most major commercial species on Georges Bank have pelagic eggs and/or larvae and, therefore, are potentially vulnerable (Hodson et al., 2007; Billiard et al., 2008). In addition, there is a potential for convergence zones on the Bank to concentrate both oil and early life stages together in near surface waters thereby magnifying deleterious effects even further. Impact 'windows' can be defined which extend from the first day of spawning until such time that larvae or juveniles have sufficient mobility to avoid contaminated areas. While it is difficult to show the impacts of oil-induced mortality on early life stages because of large and variable rates of natural mortality, a number of previous laboratory studies have shown the presence of both lethal and sublethal effects (such as reduced growth and abnormal development) in eggs, larvae and juveniles of various species exposed to oil. Since at least two commercial species are spawning every month of the year on Georges Bank (refer to Table 2-1 on Page 29), any hydrocarbon release has the potential to affect fisheries resources. Previous modeling studies have predicted the type and level of impacts that various spill scenarios on Georges Bank could have on cod, haddock, and herring stocks. Some scenarios predicted cumulative losses in excess of 20% for both cod and herring (Spaulding et al., 1983; Reed and Spaulding, 1984; Spaulding et al., 1985).

The effects of oil on adult fish in the field are difficult to study and, therefore, knowledge is incomplete. Fish have the ability to avoid contaminated areas, providing these areas are small enough. In addition, it is difficult to determine cause and effect relationships between reduced population size and oil contamination due to high levels of natural variability. A number of studies, however, have documented MFO enzyme induction in association with oil spills (Kurelec et al., 1977; Payne et al., 1984; George et al., 1995; Woodin et al., 1997; Martinez-Gomez et al., 2009). Results have demonstrated the value of the MFO biomarker in delineating areas of potential impact and whether, for instance, fisheries closures or more detailed biological effect studies may be justified. Some populations of fish and marine mammals that are under pressure, already at historic lows, or designated under SARA may have a more pronounced vulnerability. In terms of impacts on benthic organisms, the natural interaction of oil and suspended particulate matter may facilitate the transport of oil to the sea bed (Muschenheim and Lee, 2003). Concentrations of hydrocarbons in the range of 10-100 ppm may be expected to occur in bottom sediments as a result of a blowout or spill.

3.5.5 Oil Spill Countermeasures

While containment by booms and recovery of bulk oil by the use of devices such as skimmers following a spill is the first line of defence, the effectiveness of physical recovery processes for oil spilled in the open-sea is limited by logistical constraints such as high spreading rates of the spilled oil and the operational limitations of containment booms (e.g. most booms are of little or no use when wind speeds exceed 20 knots). Under ideal conditions, due to the efficiency of skimmers being linked to encounter rate, physical recovery of spilled oil can be expected to achieve a maximum of 30% (NRC, 1989). Because of this, greater emphasis is now being placed on in situ methodologies such as in situ burning, dispersion, and bioremediation methods, which require fewer response personnel, can cover large impacted areas, and do not require the storage, transport, and disposal of waste.

In situ burning involves controlled burning of oil that has spilled from a vessel or a facility. It greatly reduces the need for storage and disposal of the collected oil and the waste it generates. Oil can be successfully burned on water if the oil layer is of sufficient thickness and an adequate ignition system is available (Fingas et al., 1994). In the last decade, introduction of improved fire-resistant booms has enabled the performance of contained and controlled burns with increased burning efficiencies (Buist et al., 2005; Potter and Buist, 2008). The use of ignition promoters, emulsion breakers, and chemical herding agents can also increase the ignitability of a slick (Buist et al., 2008). Although this method is capable of rapidly removing bulk oil from the sea surface, public acceptance of the technique has not been widely received due to concerns over environmental impacts and human health and safety issues linked to the potential toxicity of burn residues and smoke. The fate of burn residues has been investigated. Guénette et al. (1995) reported that most of the burn residue of a weathered emulsified Statfjord crude oil remained buoyant. The remaining fraction was found submerged in the water column around 30 cm below the sea surface. Subsequent experiments with eight different oil types revealed that the quantity of the burn residue to remain buoyant and the portion of it that sinks were dependent on oil type (Buist et al., 1995). While residues of thicker, heavy oil slicks and weathered crude may sink when they cool down to ambient temperatures, residues of the lighter oil may not sink.

Fingas et al. (2005) analyzed the soot resulting from the burning of heavy oils and an emulsion of bitumen. It was shown that the residues are mainly resins and asphaltenes not burned in the fire and the enriched pyrogenic PAH derived from the petrogenic PAH of the oil. The PAH concentrations correlated negatively with burning efficiency. As such, attaining higher burning efficiencies reduces the amount of pyrogenic PAH in the soot.

The application of chemical oil dispersants has re-emerged as one of the major response options for oil spills, due to the availability of a new generation of products that are lower in toxicity and higher in efficiency for the treatment of more viscous oils up to 10,000 Cenlisioke (cSt) (Fiocco et al., 1999; Colcomb et al., 2005). Dispersants offer many advantages over mechanical recovery, including the ability to treat large areas quickly since they can be applied from aircraft and proven effectiveness under moderate sea states. As the efficiency of dispersants is diminished by oil weathering processes, they are typically applied within 2-5 days of spill occurrence. Dispersants are not generally able to dissipate emulsified oil in the form of a mousse. Approved dispersant products have been designed to promote the transfer of oil in surface slicks into the water column by promoting the generation of oil droplets by reducing the oil-water interfacial tension (NRC, 1989). Oil is thus removed from the surface to protect seabirds and the suspension of dispersed oil droplets and/or oil-suspended particle aggregates in the water column minimizes the adverse risk of petroleum hydrocarbon contamination to the benthic community. This countermeasure technique is based on the premise of promoting the dilution of oil to concentrations below toxicity threshold limits for water-borne organisms and has been demonstrated under operational conditions (Lunel et al., 1997).

Furthermore, sufficient dilution of petroleum hydrocarbons in the seawater has the advantage of facilitating un-inhibited biodegradation of hydrocarbon compounds. Biodegradation can be compromised either due to self-inhibition at high concentrations, restriction caused by limited nutrient supply at high oil loading, or reduced bioavailability because of limited oil-water interfacial area.

A recent study that has been conducted by DFO's Center for Offshore Oil, Gas and Energy Research (COOGER), in collaboration with the Unites States Environmental Protection Agency (U.S. EPA), has demonstrated the chemical dispersant effectiveness for a variety of crude oils under various sea mixing energy conditions (Lee et al., 2009). The study found that the use of chemical dispersants significantly increases the amount of oil dispersed in the water column and changes the dispersed the droplet size distribution (Li et al., 2009b; Li et al., 2009c; Li et al., 2009d). Another alternative oil spill response measure for smaller spills in the open-sea is based on the enhancement of physical dispersion of oil through the formation of stable OMA that stimulate oil removal in the water column via microbial biodegradation (Lee, 2002, Lee et al., 2002; Lee et al., 2003; Lee et al., 2008). Studies on the toxicity of dispersed oil are currently underway to develop operational guidelines for the application of these oil spill countermeasures. For the remediation and restoration of petroleum hydrocarbon contaminated shorelines, DFO scientists have been involved in research, development, and technology transfer of bioremediation as one of the most cost-effective and eco-friendly decontamination technologies (Venosa et al., 1996; Lee and De Mora, 1999; Owens et al., 2003; Sergy et al., 2003).

Bioremediation, a strategy based on the enhancement of oil degradation rates by living organisms (Leahy and Colwell, 1990; Margesin et al., 2003), has been considered to be a potential secondary treatment option in oil spill cleanup operations, as well as a primary response strategy for the cleanup of environmentally sensitive areas that are not amenable to conventional cleanup techniques and/or with a low-level petroleum hydrocarbon contamination (Venosa and Zhu, 2003). This remediation strategy has several potential advantages over conventional technologies: it is less costly; less intrusive to the contaminated site; and, when applied in situ, generates no wastes with the end products being benign to the environment. Existing bioremediation strategies are essentially linked to biostimulation and/or bioaugmentation treatments. Marine waters typically have low concentrations of nitrogen and phosphorus, which limit the optimal rates of oil degradation following a spill. Biostimulation by the addition of fertilizers has been reported to enhance the rate and extent of crude oil degradation under field conditions (Lee et al., 1993; Prince, 1993; Rosenberg et al., 1993; Bragg et al., 1994; Lee et al., 1995, Swannell et al., 1996; Venosa et al., 2002; Prince et al., 2003b). Bioaugmentation consists of the addition of known oil-degrading bacteria that are non-native to the contaminated sites, in order to supplement the existing microbial population of clean up wastes (Azarowicz, 1973; Bartha, 1986; Forsyth et al., 1995).

Fisheries and Oceans Canada scientists have been involved in research, development, and technology transfer of bioremediation as one of the most cost-effective and eco-friendly decontamination technologies (Venosa et al., 1996; Lee and De Mora, 1999; Owens et al., 2003; Sergy et al., 2003). Bioremediation efforts have been concentrated in shoreline and wetland environments. This is due to the fact that effective biodegradation treatment of an oil spill is likely to take longer than the period for an oil slick to reach the coast (NRT, 2000). It is also difficult to maintain elevated nutrient concentrations in an open system where rapid dilution processes occur (Leahy and Colwell, 1990). To date, bioremediation field trials have consistently shown that bioaugmentation seems to have little benefit for the treatment of spilled oil in an open environment (Nichols and Venosa, 2008). In Canada, a screening protocol has been designed to evaluate the hydrocarbon degradation efficacy of oil spill bioremediation agents (Blenkinsopp et al., 1995). Products that pass the test of efficacy and toxicity are assumed to have a good potential application in spill cleanup. This does not ensure a successful outcome when applied in a real scenario, however, since the commercial culture still has to survive in the foreign and possible hostile environment, effectively compete with the indigenous microorganisms, and overcome any limitation of mass transfer.

In terms of impacts of oil spills and blowouts, there is always a trade-off of risks of oil contact or toxicity to different marine species. When oil is diverted from the surface slick into the water column risks to the avian species are diminished. Oil in the water column, however, may be more toxic to pelagic and benthic species due to the increased percentage of dissolution of lighter and more toxic components that would otherwise evaporate to the atmosphere if left on the surface of the slick. Dissolution of less soluble components is also facilitated by dispersion in the water column, which increases the oil-water interfacial area. Use of dispersants to enhance dispersion of oil to the water column may also incur increased bioavailability of toxic components to the pelagic organisms (Ramachandran et al., 2004; Couillard et al., 2005; Schein et al., 2009).

3.6 INFRASTRUCTURE, OPERATIONS, AND DECOMISSIONING

3.6.1 Marine Noise

In addition to the noise of airguns used for seismic exploration, a significant amount of noise is generated during the exploration, construction, production, and decommissioning phases of offshore oil and gas development. The sound levels and frequency emitted is dependent on the source, such as the operation of hull mounted machinery, dredging operations linked to construction, and the use of explosives for decommissioning, to name a few The biological impact of sound levels is linked to the hearing threshold (i.e. detection level) of the organism in question, alterations in behavioural response such as avoidance, habituation (diminished sensitivity with exposure) and sensitization (increased sensitivity with repeated exposure), and temporary or permanent hearing impairment. It should be noted that the ocean is not quiet. Sources of constant ambient sound include breaking ice, waves, tidal currents, shipping traffic, and earthquakes, to name a few.

Biological sound sources can be significant. For example, Stafford et al. (1998) recorded blue whale calls over a distance of 600 km. Both natural and anthropogenic sounds can mask (i.e. drown out) weak sound signals from distant sources. Desharnais and Collins (2001) suggested that oil and gas development activities had a smaller effect on the background noise field on Sable Bank than fishing, shipping, and fin whales. Of the various sources of sound in the ocean, seismic surveys associated with oil and gas exploration has attracted the most attention. Payne (2004), however, has raised concern over other sources of chronic sound exposure such as those associated with ship traffic lanes. While the noise levels from these sources may not induce physical injury to marine life, they may interfere with normal communication and behavioural functions.

3.6.2 Influence of Light

Seismic vessels, offshore drilling/production platforms, floating production storage and offloading units, and service vessels are all equipped with navigation and work lights for safety of operations at night. Sea birds are typically attracted to sources of light. Some plankton and pelagic species, such as squid, may also be attracted to the lights and subject to higher predation at the surface due to their aggregation. Drill rigs and production platforms may also have flares that produce high levels of light and heat during periods of operation.

3.6.3 Disposal of Wastes

There are a variety of liquid and solid wastes produced during exploration and production operations, in addition to drilling muds and fluids, drill cuttings, and produced water, as described in previous sections. Additional waste materials may include sanitary/domestic waste water, cooling water, bilge water, ballast water, and garbage. Sewage and food wastes are typically macerated and treated to some degree, before disposal at sea with other liquid wastes. Considering the volume discharged and the level of dilution with tides and currents, the discharge of liquid domestic wastes and sewage is expected to cause negligible effects on fish species. In Nova Scotia's offshore, under the Offshore Waste Treatment Guidelines and the Nova Scotia Offshore Petroleum Drilling and Production Regulations, all solid wastes are to be brought to shore for treatment and disposal.

Excess chemicals or chemicals in damaged containers are also returned to shore on supply vessels. The Transportation of Dangerous Goods and Workplace Hazardous Materials Information System (WHMIS) regulations govern the handling, use, storage, transport, and disposal of hazardous materials and substances. The Guidelines also encourage operators to minimize volumes of wastes generated by their operations and to minimize the quantity of substances of potential environmental concern. In addition, offshore operators must adhere to the Offshore Chemical Selection Guidelines for Drilling and Production Activities on Frontier Lands, as well as other relevant sections pursuant to the International Convention for the Prevention of Pollution from Ships with respect to marine drilling discharges and emissions. Prior to entering Nova Scotia's offshore, offshore petroleum operators are required to evaluate chemical substances used in their operations to ensure that those used are the most environmentally appropriate. In addition, all drilling operators must work within the framework of a corporate management system that includes an Environmental Protection Plan and Waste Management Plan, which outline corporate and regulatory requirements and procedures for the handling, treatment, and disposal of discharges and wastes. Cement slurry and blowout preventer fluids may also be discharged during drilling operations. Mitigation of impacts is largely based on the selection of low toxicity products, as described in the Offshore Chemical Selection Guidelines and limited discharge volumes.

Last, solid operational debris, such as anchors and chains from offshore activities, has been a problem in the North Sea and the Gulf of Mexico. Canadian drilling regulations, however, require that the sea floor be cleared of any material that could interfere with other commercial uses of the area when a well is abandoned, unless otherwise determined by the regulator. Typically, the well casing itself must be sealed at least 1 m below the sea floor to prevent damage to fishing gear. In a year of the cessation of the U.S. exploration activities on Georges Bank, only four large items remained unrecovered in the area. None of them exhibited sufficient interference with commercial fishing activities (Danenberger 1983).

3.6.4 Atmospheric Emissions

Atmospheric emissions are associated with all stages of oil and gas activities. The main sources atmospheric emissions include:

- operation of oil or gas fired generators, pumps, turbines, and engines on the platform, ships, and onshore facilities;
- evaporation or venting of hydrocarbons during different operations of their production, treatment, transportation, and storage; and
- burning of gas and hydrocarbons during well testing and development, as well as flaring to eliminate gas from storage tanks and pressure-control systems.

Flaring is typically the major source of atmospheric emissions from offshore oil and gas operations. Numerous pressure relief valves on pressure vessels would occasionally vent natural gas, but instead of being released to the environment, vented material goes up the flare stack and is burned producing carbon dioxide.

Flares are typically 80-98% efficient at converting hydrocarbons to carbon dioxide. Flaring serves two functions:

- in the event of an accident or leak, operators may need to depressurize the facility whereby natural gas is sent into the flare stack and burned off; and
- under normal operating conditions, the flare serves to control and reduce emissions.

From an ecological perspective, the most hazardous components associated with flaring are nitrogen and sulfur oxides, carbon monoxide, and the products of the incomplete burning of hydrocarbons. These interact with atmospheric moisture, transform under the influence of solar radiation, and can precipitate back to the Earth's surface where they may increase local and regional pollution. To date, atmospheric emissions from installations in the offshore of Atlantic Canada have not been of major concern to regulatory agencies due to the scalc of emissions, distance from populated areas, and dispersion by offshore winds.

3.6.5 Decomissioning

Typically, offshore exploratory wells are abandoned and decommissioned by the removal of the wellhead and mechanical severance below the sediment surface. Detonation of explosives below the mud line may be used if mechanical severance proves difficult. In general, all infra-structure installed for production are removed once the site is abandoned, unless otherwise permitted by the regulator.

3.7 OTHER OFFSHORE PETROLEUM REGIONS

3.7.1 Scotian Shelf and Grand Banks

The Scotian Shelf and Grand Banks, which are to the east of Georges Bank in the Northwest Atlantic, currently support a number of petroleum activities. The Scotian Shelf is a broad continental shelf off the coast of Nova Scotia. It has a sand, gravel, and cobble bottom on the top of the banks with gravel and finer sediments in the deeper basin areas. There are proven hydrocarbon resources (e.g. the Cohasset-Panuke oil field, the Sable Project gas field, and the Deep Panuke gas field) all on the shallow Scotian Shelf (Kidston et al., 2007). In addition, exploration activities are targeting the deep water areas (e.g. the Scotian Slope), since advancing technologies have enabled hydrocarbon discoveries and high success rates in deep water of other circum-Atlantic basins such as the Gulf of Mexico, offshore Brazil and West Africa, and recently Northwest Africa (e.g. Mauritania) (Kidston et al., 2007). The Scotian Shelf basins and Scotian Slope remain virtually unexplored, with the potential for significant hydrocarbon discoveries.

Operators are required to meet certain regulatory requirements before the CNSOPB can approve any offshore petroleum activities. The regulatory framework which governs offshore petroleum operations consists of legislation, regulations, guidelines, and policies, as overseen by the CNSOPB. The CNSOPB's resource conservation approach is designed to ensure that operators are committed to resource conservation, to audit activity authorization applications from a resource conservation perspective, and to perform necessary studies and surveillance in order to develop and support an independent understanding of the resource. On the Scotian Shelf, much of the fisheries yield is directed toward demersal fish stocks, and the protection of fisheries resources has been a priority. Commercial scallop stocks are found on the Scotian Shelf and these are recognised as major valued ecosystem components in the SOEP EEM Program.

In an ecosystem assessment report for the Eastern Scotian Shelf Integrated Management (ESSIM) area, Zwanenburg et al. (2006) noted that oil and gas activities would likely not have caused significant overall loss of biodiversity due to the relatively small proportion of the ESSIM area affected by related activities and the modest scope of exploration (and development) having been conducted to date. Several ecosystem status reports for the Scotian Shelf (e.g. Breeze, 2002; DFO, 2003b; Zwanenburg et al. 2006), however, have suggested that the cumulative effects of human use activities (e.g. fishing, commercial shipping, naval operations, and offshore oil and gas activities) may act additively and/or synergistically to impact the marine ecosystem. Hurley (2009) noted that two assessment reports concluded that the eastern Scotian Shelf ecosystem has been profoundly altered over the past few decades mainly by fishing, which occurred against a backdrop of a dynamic biophysical environment. The result has been a significant decrease in the biomass of demersal groundfish species and a significant increase in biomass of grey seals, small pelagic species, commercial crustaceans, and phytoplankton.

The Grand Banks is a large bank system off eastern Newfoundland with significant biodiversity, as well as hydrocarbon resources. Much of the biological production is demersal fish species. Although there are some Icelandic scallops, there are no significant scallop or lobster fisheries in the vicinity of the petroleum development sites (Boudreau et al, 1999). There are five major petroleum fields on the Grand Banks: Hibernia, Terra Nova, Hebron, White Rose, and Ben Nevis fields. Only Hibernia, Terra Nova, and White Rose have been developed with 67, 34, and 24 development wells drilled, respectively (CNLOPB website). Similar to the projects in the offshore of Nova Scotia, these projects are required to meet certain regulatory requirements as contained in the Statutes and Regulations governing the CNLOPB.

3.7.2 North Sea

The North Sea is a relatively contained shallow sea on the European continental shelf. It has a mean depth of approximately 90 m, with the exception of the Norwegian trench that has a maximum depth of 725 m. It has low tidal energy and lower average physical forcing, which results in more stratified waters compared to Georges Bank. In addition, the environment is less dispersive than Georges Bank due to weaker currents. This results in discharges from drilling platforms accumulating close to the site and may cause more severe local ecosystem impacts (Kingston, 1992; Olsgard and Gray 1995; Daan et al, 1996; Boudreau et al, 1999). Much of the petroleum activity is concentrated in the southern North Sea and takes place within 150 km to land. This places the potential impacts much closer to human populations that live around the North Sea. The population in the drainage basin of the North Sea is on the order of 150 million people. This larger population, shorter distances, and weaker circulation system results in higher background levels of pollution than are observed on the Georges Bank area (Boudreau et al, 1999).

3.7.3 Gulf of Mexico

The Gulf of Mexico is an ocean basin largely surrounded by the North American continent (Gulf coast of the United States and northern Mexico), with Cuba on its eastern boundary. It includes both tropical and temperate climate regimes with some coral reefs. Its mean sea surface temperatures range from 28-30°C and 20-24°C in the summer and winter, respectively (Boudreau et al, 1999). The tidal range in the Gulf of Mexico is approximately 0.3 m, with semi-diurnal tides in the east and diurnal in the west. The Gulf provides habitat for a large range of tropical species of fish, warm water invertebrates, and marine turtles. Sea turtles have associated nesting beaches in the Gulf. There are fewer large whales compared to Georges Bank, although offshore in deeper waters there is a resident population of sperm whales (Boudreau et al, 1999). The Gulf of Mexico is not as pristine an environment as Georges Bank, as it receives large amounts of freshwater, sediment, and nutrient inputs, particularly from the Mississippi River. The Gulf of Mexico supports a large number of petroleum production projects (Table 3-11).

Table 3-11. Number of wells in the Gulf of Mexico by water depth. Data as of June 8, 2009 (USBEM, 2010).

Water Depth (m)	Approved Drilling Permits	Active Leases	Active Platforms
0 - 200	33423	2740	3676
201 - 400	1095	186	21
401 - 800	827	-	9
801 - 1000	486	409	7
> 1000	1522	3343	23

The Gulf of Mexico Offshore Operations Monitoring Experiment (GOOMEX) was undertaken from 1992 to 1995 to develop and recommend sensitive and appropriate techniques for monitoring activities of offshore oil and gas production. To accomplish this goal, a broad range of biological, biochemical, and chemical methodologies were tested to detect and assess potential chronic, sublethal, and long-term effects of offshore oil and gas production. The GOOMEX study components included measurements of abiotic characteristics to indicate environmental state (e.g. chemical patterns in sediments and water, geological patterns, and physical patterns) and biotic responses (e.g. tissue body burdens, detoxification response by fish and invertebrates to contaminant exposure, sediment toxicity to invertebrates, meiofaunal, macrofaunal and megaepifaunal community structure, harpacticoid reproduction and population genetic structure, and megaepifaunal reproduction).

In general, the biological patterns observed around platforms in the Gulf of Mexico have been the result of the complex interactions of variations in sediment grain size, organic matter enrichments, and toxic response to contaminant exposure. Contaminant levels only exceeded levels thought to produce deleterious biological effects at a few stations close to the platform, with the effects being limited to 100 m from platforms. Relative to background (i.e. 200 m), the zone near platforms had sediments with higher levels of contaminants and toxicity, reduced levels of abundance, species diversity, genetic diversity, and reproductive success, and feeding guilds with more deposit feeders. While further study is needed, the results of GOOMEX suggest that benthic environments around platforms have been disturbed as a result of the presence of the platform and discharges derived from exploration and production activities (Kennicutt 1995).

3.8 CONCLUSION

Concern over the potential environmental impacts from offshore petroleum development and production is largely linked to the possible exposure of marine organisms to seismic noise, operational waste discharges (e.g. drill wastes, produced water, and other associated wastes), and accidental oil spills and/or blowouts. The impacts of seismic noise to fish and invertebrates include mortality of eggs and larvae, sub-lethal effects, and changes in fish swimming patterns. Mortalities likely occur within a few metres of the sound source, although little is known about whether acute high level sound exposures or chronic low level exposures adversely affect marine organisms at some depth in the water column. In addition, there is conclusive evidence demonstrating the impact of seismic noise on fish behaviour and fisheries catch success. For marine mammals, although there are no definitive case studies linking mortality resulting from exposure to oil and gas exploration seismic surveys, there is evidence that exposure to seismic sound can result in dispersion and/or temporary displacement of animals. Since behavioral observations of marine mammals are typically variable, some findings are contradictory, and the biological importance of observed effects has not been measured. While impacts to individuals or groups of marine organisms have been observed, there is ongoing debate/investigation over the potential for population or ecosystem scale impacts. In addition to sound, a drilling rig and its associated supply vessels generate light during routine operations. While marine mammals may avoid the immediate area around a rig due to the unusual and/or increased lights, marine birds and pelagic species, such as squid, may be attracted to the lights of the offshore installation or service vessel.

Drilling wastes (i.e. spent drilling mud and well cuttings) are of primary concern during exploration and development drilling operations. In recognition of the results from toxicity studies, current regulatory guidelines in Canada require the recovery and onshore disposal of drill cuttings generated with the use of OBM, when possible. If re-injection of drill solids associated with SBM or Enhanced Mineral Oil Based Muds is not possible, the solids may only be discharged at the site following treatment with best available technology. In contrast, low toxicity WBM is permitted to be discharged. Drilling muds can have both acute (i.e. lethal) and sublethal impacts on marine organisms. Acute effects are predominantly associated with the smothering of slow-moving or sessile benthic organisms near the point of discharge. Sublethal or chronic, long-term impacts such as reduced growth or reproduction may also be associated with sessile benthic organisms if they become exposed to drilling mud components that have settled on the bottom. The magnitude of potential toxic effects is directly linked to exposure time and concentrations (i.e. dosage). Operational models predicting the fate and transport of drilling waste have been coupled with biological effects data to enable the risk assessment of drilling waste disposal.

Under field conditions, drilling muds and cuttings undergo a number of physico-chemical processes in the marine environment following discharge including: (1) advection, (2) dispersion, (3) aggregation (4) settling, (5) deposition, (6) consolidation, (7) erosion, (8) re-suspension, (9) re-entrainment, and (10) change in bed elevation. Documented results from numerous case studies on water based muds suggest that the degree of impact of drilling fluids and cuttings on benthic and demersal species is highly dependent on a number of local environmental variables (e.g. depth, current and wave regimes, and substrate type), as well as on the nature and volume of the discharges, including cuttings size and location of the outfall in the water column. Numerical models have been developed to improve our knowledge on the probable fate and effect of particles and chemicals associated with drilling wastes discharged into the sea. Integration of risk assessment models with physical transport/fate and effect models, will help to evaluate site-specific risks from drilling waste discharges.

There is consistency in the results of EEM studies from various Canadian East Coast programs despite differences associated with the volumes and type of drilling waste discharges, scale and location of drilling, and variations in EEM sampling programs. The highest levels of drill waste (sediment and body burden concentrations) were associated with multiple-well, production-based fields that had been operating for several years in the offshore Newfoundland area. While sampling stations have extended out from the immediate vicinity of platforms to tens of kilometers away for reference sites, study results have demonstrated that changes in the diversity and abundance of benthic organisms have been generally limited to within 1000 m of the drill site and returned to baseline conditions within 12 months of cessation of drilling discharges. The spatial area for observed biological effects was generally smaller than the area over which drilling muds were detected.

Produced water, a complex mixture of inorganic salts, metals, radioisotopes, production chemicals (e.g., biocides and emulsion breakers), and a wide variety of organic chemicals (e.g., organic acids, petroleum hydrocarbons, and phenols) in both dissolved and particulate phases, represents the largest volume (up to 80%) waste stream in oil and gas production operations. The physical and chemical properties of produced water vary widely depending on the age, depth, and geochemistry of the hydrocarbon-bearing formation, as well as the chemical composition of the oil and gas phases in the reservoir. The chemicals of greatest environmental concern in produced water, because of their potential for bioaccumulation and toxicity, are metals and hydrocarbons. While their concentration in the produced water stream is generally below the effects threshold, in some regions there has been concern that highly-alkylated phenols (octyl- and nonyl-phenols), which are well-known endocrine disruptors and some toxic production treatment chemicals, may cause localized effects. If water depths are shallow, some metals (e.g., barium, iron, and manganese) and higher molecular weight aromatic and saturated hydrocarbons may accumulate in sediments near produced water discharges, possibly harming bottom living biological communities.

In Canada, the formulation of regulatory guideline values for produced water discharge is an adaptive process that promotes the development of improved EEM programs that takes into consideration the level of environmental risk, Best Available Technology for mitigation measures, and socio-economic benefits. The current regulatory guidelines for produced water discharge in Canada (i.e. Offshore Waste Treatment Guidelines) are based on petroleum hydrocarbon content. Treatment of produced water for regulatory compliance before ocean discharge removes solids and non-aqueous liquids from the waste water, including dispersed oil, suspended solids, scales, and bacterial particles, as well as corrosive gases, such as carbon dioxide and hydrogen sulphide. Existing clean-up protocols for produced water are effective in removing volatile compounds and dispersed oil from the produced water, but not the dissolved organic and inorganic fractions. Treated produced waters on offshore platforms are typically discharged below the sea surface at a depth from 10-100 m.

The various models used to predict the fate of produced water (e.g. plume dispersion models and chemical fate/transport models) differ in specific details, but all predict a rapid initial dilution of discharges by 30- to 100-fold in the first few tens of meters of the discharge, followed by a slower rate of dilution at greater distances. Factors that affect the rate of dilution of produced water include discharge rate and height above or below the sea surface, ambient current speed, turbulent mixing regime, water column stratification, water depth, and differences in density (as determined by temperature and total dissolved solids concentration) and chemical composition between the produced water and ambient seawater. Based on the chemical composition of treated produced water and predicted dispersion rates for potential sites of concern, it is expected that toxicity threshold limits for acute effects are not likely to occur beyond the immediate vicinity of the discharge pipe for offshore platforms located on the East Coast of Canada, due to natural dispersion processes driven by tides and currents. Over the 15 to 20 year life-span of a typical offshore platform, however, there is concern that continual long-term chronic exposures to produced water discharges may cause sub-lethal changes in marine organisms.

It has recently been suggested that the toxicity of produced water may diminish over time following its discharge, due to natural chemical kinetic reactions that occur following its release (in an anoxic state) into the open ocean. Due to the differing rates of degradation of the multiple toxic components in produced water and the variation of ecosystem effects resulting from differences in toxicity, modeling efforts have been employed to try to account for the variations and determine the general ecological risks associated with produced water discharge overtime. The accuracy of contaminant risk assessment models is dependent on the identification and quantification of the various chemicals that induce the toxic effects. Additional information on the toxicity of produced water components will improve the accuracy of the Environmental Impact Factor model currently used for risk assessment of produced water discharges. In regard to other wastes, the *Offshore Waste* Treatment Guidelines, Nova Scotia Offshore Petroleum Drilling and Production Regulations, and domestic waste treatment technologies recommended by the Department of the Environment are in place to mitigate the potential risks associated with the disposal of domestic waste from offshore facilities. Furthermore, under Canadian drilling regulations, solid operational debris (e.g. anchors, chains, etc.) on the sea floor is to be removed when a well is abandoned.

For offshore oil and gas exploration and production activities, the risk and consequence of oil spills is of the greatest environmental concern. From a socioeconomic perspective however, tainting and contamination of fisheries resources leading to closures would be of greatest concern. Although there is a low probability of occurrence, spills, blowouts, and malfunctions can result in the release of liquid and gaseous hydrocarbons. Blowouts occur when operators are unable to control the flow of oil or gas and it is released into the atmosphere or surrounding water. Oil spills other than from blowouts can occur during drilling and production activities. These include spills of diesel oil or lubricating oil for operations on the platforms, as well as spills from transfer and transport operations. In general, spills are usually small and have minimal/negligible environmental impact. Larger spills, however, can occur. In addition to accidental releases, a significant amount of crude oil, estimated between 4.2-14 million barrels, is discharged each year from natural seepage. Natural seepage accounts for the largest, cumulative source of oil that enters the ocean. In the North Atlantic, the occurrence of natural oil seeps has been well documented from the Canadian Arctic to the Gulf of Mexico, including the Georges Bank region.

Scientific studies on the transport and effects of petroleum hydrocarbons (i.e. gas, gas condensate, and/or oil) from spills and blowouts have been ongoing for decades. In the event of an accidental release of gas, it is anticipated that much of it would be rapidly dissipated into the atmosphere with the assistance of the wind. While a large fraction of gas condensate would evaporate, some components such as benzenes and naphthalenes may elicit an acute toxic effect near the point of release depending on duration, timing, and location of the event. The release of crude oil may result in a surface slick that eventually becomes entrained in the water column and/or become incorporated into sediments. Oil concentrations on the order of 100 ppb have been demonstrated to cause both lethal and sublethal effects on planktonic organisms in laboratory studies. It has been difficult, however, to demonstrate that either major spills or chronic oil input have any irreversible impacts on the marine planktonic communities. For fish and marine invertebrates, the major concern is a spill incident that coincides in the time and place of a fish spawning event. Benthic organisms, such as scallops, are also susceptible to exposure. Residual hydrocarbons may not persist in surficial sediments over an extended period, due strong currents that could continually disperse and transport fine sediment particles over a wider area and into deep waters. To predict spill trajectories, a number of oil spill models and operational tools (e.g. tracker buoys) covering a range of capabilities, from simple trajectory models to 3D trajectory and fate models, are in use in the world today. The application of predictive models is also used to support risk assessment studies and operations to provide critical guidance for contingency planning as well as clean-up operations.

In the offshore of Nova Scotia, individual operators have the responsibility to implement a corporate Emergency and Oil Spill Response Plan approved by the CNSOPB that includes routine spill response exercises. Physical containment and recovery of bulk oil is generally considered the first line of defense following a spill. The effectiveness of physical recovery processes for oil spilled in the open-sea is limited by logistical constraints (e.g. the spreading rate of oil spills and operational limitations for containment booms), but mostly by weather (e.g. sea state) which is the largest limiting factor to containment and recovery. As a result, there is a renewed interest regarding the application of chemical dispersants, which promote the transfer of oil on the surface into the water column by promoting the generation of oil droplets. This countermeasure technique is based on the premise of promoting the dilution of oil to concentrations below toxicity threshold limits for water-borne organisms. Furthermore, the dispersion of oil into the water column will enhance the biodegradation rates of residual hydrocarbon compounds. Decisions on chemical oil dispersant use should include a net benefit analysis. While the application of dispersants would reduce the contact between seabirds and surface oil slicks, and the probability of oil impacting shoreline environments, there is concern that they may also increase the bioavailability of toxic components to pelagic organisms. With advances in scientific knowledge, improvements are continually being made in the areas of prevention, environmental effects monitoring, risk assessment, mitigation, and remediation of potential impacts to the marine environment associated with offshore petroleum development and production activities.

4.0 FISHERIES AND OTHER OCEAN USERS

This chapter outlines the Aboriginal fisheries, commercial fisheries, and other oceans users in and around the Georges Bank moratorium area. It also outlines potential interactions that may occur between existing ocean users and activities that are typically associated with offshore petroleum exploration and development. Certain information presented in this chapter is an update to 'The Scotian Shelf: An Atlas of Human Activities' (DFO, 2005b). The human use figures are used to demonstrate the importance of the moratorium area for fisheries relative to the Scotian Shelf. Fishery landings data presented in the figures is aggregated over more than one year and does not reflect fishery patterns over seasonal or annual timescales. The following chapter, Chapter 5.0, outlines the landings, landed values, and estimated employment associated with the fisheries of the area. Typically, reference to Georges Bank in the following fisheries sections refers to that portion of the Bank in Canadian waters and not the Bank in its entirety.

4.1 ABORIGINAL FISHERIES

Sixteen First Nations in the region and the Native Council of Nova Scotia are fishery licence holders, which may afford Aboriginal groups the opportunity to fish on Georges Bank for Food, Social, and Ceremonial purposes and commercial communal fishing. The Government of Canada may be required to consult Aboriginal groups regarding a potential decision on the future of the moratorium that may affect their fishing activity and, where appropriate, accommodate their interests (Government of Canada, 2011).

4.2 COMMERCIAL FISHERIES

The commercial fisheries of Georges Bank have had a storied past. In the years following World War II, intense fishing activity by foreign and domestic fleets left many fish stocks in the area near collapse. In response, Canada and the United States, following declaration of their 200-mile exclusive economic zones and settlement of the international boundary dispute, instituted joint management programs that have contributed to the rebuilding of stocks in the area. Today, scallop, lobster, and haddock populations have recovered to healthy stock levels, while pelagic fisheries stock levels remain relatively stable. Last, groundfish fisheries stock levels (other than haddock) remain low or depleted. Despite this, Georges Bank and the Northeast Channel remain some of the most important fishing areas in the Northwest Atlantic Ocean. Many commercial fisheries may operate in the area at different times of the year, subject to fishing season and total allowable catches (Figure 4-1).

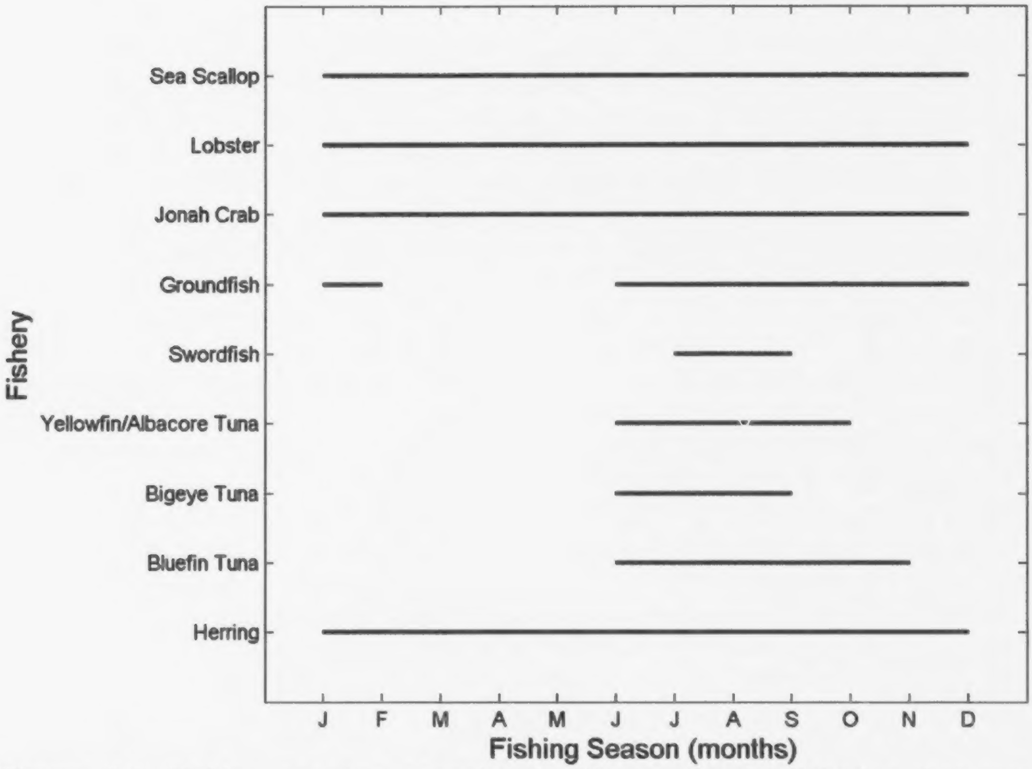


Figure 4-1. Fishing seasons associated with commercial fisheries that may operate in the moratorium area. All fishing seasons are subject to reaching a total allowable catch (TAC), with the exception of the yellowfin tuna fishery that has no TAC.

The Convention Area of the Northwest Atlantic Fisheries Organization (NAFO) defines divisions which are used to manage groundfish fisheries of the Northwest Atlantic. The Maritimes Region of Fisheries and Oceans Canada (hereafter referred to as 'DFO Maritimes Region') corresponds to divisions 4V, 4W, 4X, and parts of 5Y and 5Z. The Georges Bank moratorium area includes portions of NAFO Divisions 4X and 5ZE. The Atlantic Fishery Regulations (1985), pursuant to the *Fisheries Act*, provide management measures and delineate management areas for many fisheries in Atlantic Canada. The NAFO Divisions are included in the regulations, as are other fishing areas such as Scallop Fishing Areas, Lobster Fishing Areas, Crab Fishing Areas, and Herring Fishing Areas, to name a few.

An active commercial fishing licence is a fishing licence that is accompanied by licence conditions (both a licence and licence conditions are required to fish). In the DFO Maritimes Region, 1783 active commercial fishing licences are currently issued that permit fishing in the Georges Bank moratorium area. This section provides an overview of the management of commercial fisheries in the area, including: shellfish fisheries (i.e. sea scallop, lobster, and crab); groundfish fisheries (i.e. cod, haddock, and yellowtail flounder); and pelagics fisheries (i.e. swordfish, tuna, herring, and other pelagic species such as mahi mahi and shark).

4.2.1 Shellfish Fisheries

4.2.1.1 Scallop Fishery

Canada's participation in the scallop fishery began in 1945 marked by the first landings of scallops from Georges Bank by an offshore vessel (the fishery only operates in the DFO Maritimes Region of Canada). Today, landings from the Georges Bank area, on average, account for approximately 70-80% of the annual scallops landed in Canada (Figure 4-2). The scallop fishery in the region consists of 6 active licences. Licence holders operate 6 freezer vessels and 12 vessels without freezer capability (i.e. wetfish vessels); some licences allow multiple vessels to be used. Freezer vessels have a crew of 25-32 individuals and wetfish vessels 17-19 individuals. Freezer vessels are the largest of the scallop fleet and are generally greater than 40 m in length. The wetfish vessels are generally greater than 27 m in length. Most scallop vessels fish year round, with the duration of fishing trips varying from 10-12 days on wetfish vessels and up to 22 days on freezer vessels. The scallop fishing fleet uses a New Bedford scallop rake or drag, which consists of a metal frame 4-5 m in width and an attached bag of metal rings. In practice two drags are fished simultaneously; one on each side of the vessel.

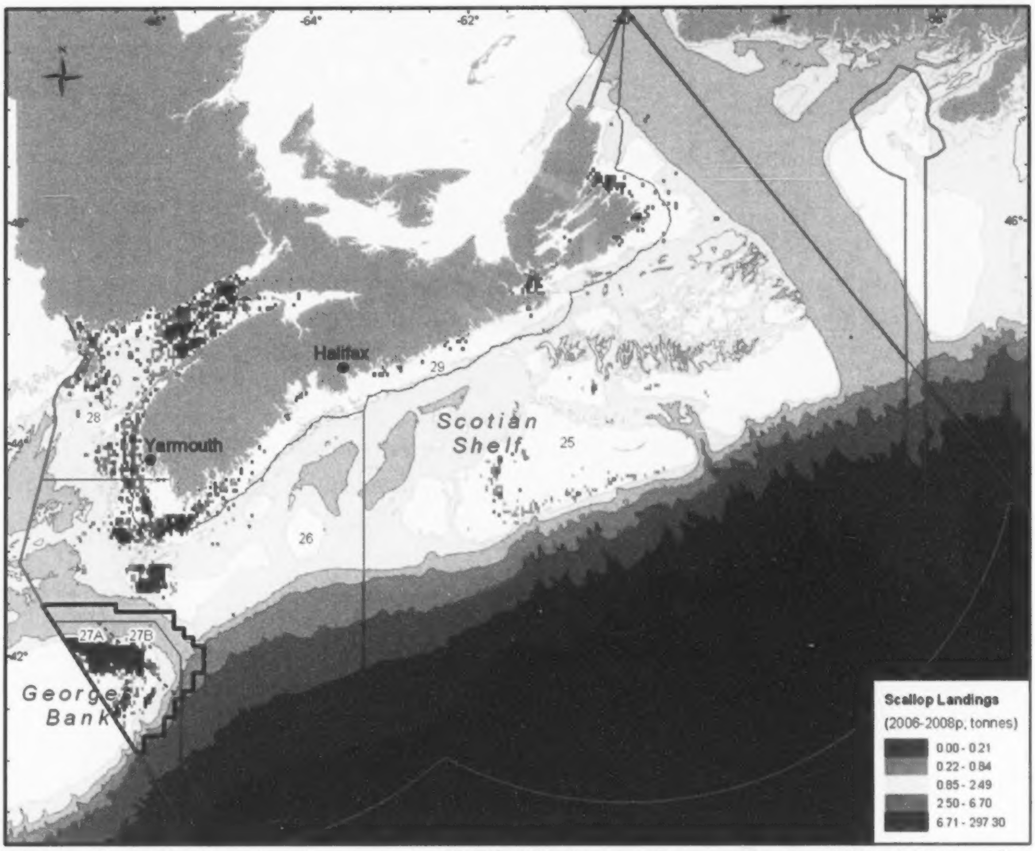

-64°
-62°
46°
44°
42°
Halifax
Yarmouth
29
28
Scotian Shelf
25
26
27A
27B
Georges Bank
Scallop Landings
(2006-2008p, tonnes)
0.00 - 0.21
0.22 - 0.84
0.85 - 2.49
2.50 - 6.70
6.71 - 297.30

Figure 4-2. Scallop landings in the DFO Maritimes Region from 2006-2008p. The 'p' refers to preliminary data for 2008. The purple lines represent the Scallop Fishing Areas.

The fishery in proximity of the moratorium area occurs in Scallop Fishing Area (SFA) 27 (Figure 4-2). The area is split into two sub-management units known as Georges Bank A and Georges Bank B. The key management measure in the scallop fishery is the administration of a Total Allowable Catch (TAC) system. From 1998 to 2008, there has been variation in the annual TAC for the Georges Bank A and Georges Bank B sub-management units. In the late-1990s, the TAC of Georges Bank A declined from 3200 to 2500 tonnes, or t (Figure 4-3). This increased to an average of 6300 t from 2000 to 2003, before returning to a low of 2500 t in 2004. Since 2004, the TAC of Georges Bank A has increased to 5500 t in 2008. In contrast, the TAC of Georges Bank B has typically been much less than that of Georges Bank A (Figure 4-3). In the late-1990s, the TAC of Georges Bank B increased from 800 to 1200 t, although it has been at an approximate average level of 250 t from 2000 to 2008.

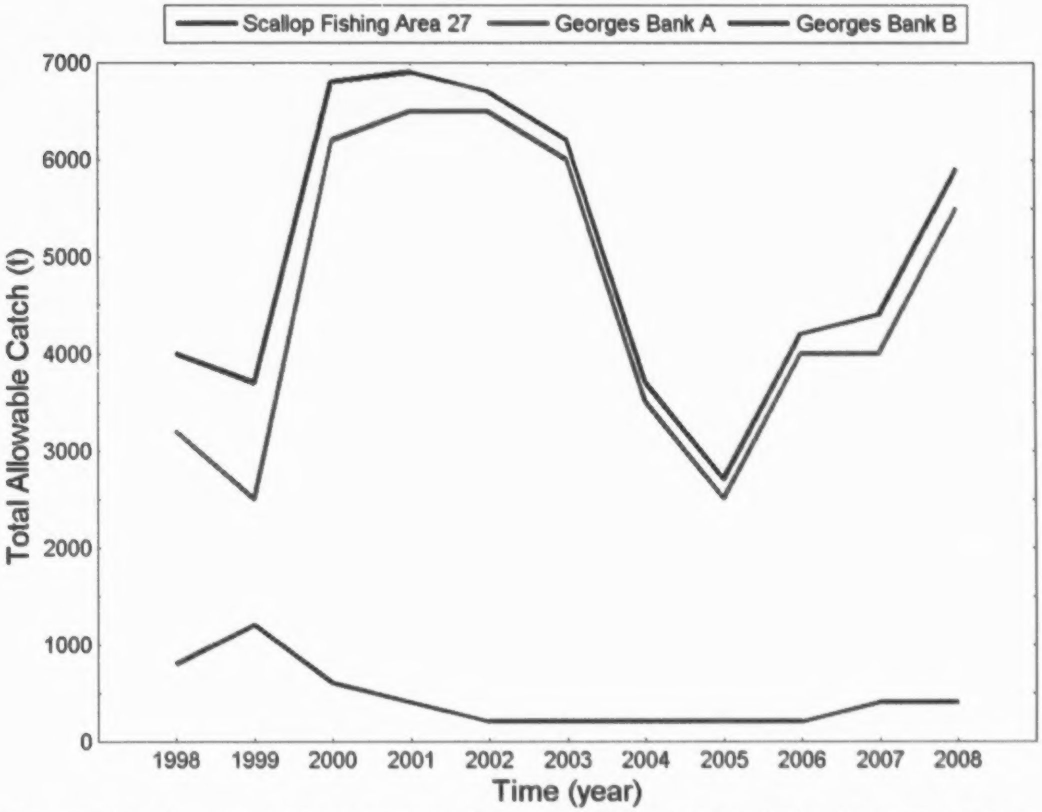


Figure 4-3. Scallop fishery annual Total Allowable Catch limits (t) from 1998 to 2008 set for Scallop Fishing Area 27 (black line) and its sub-management units Georges Bank A (red line) and Georges Bank B (blue line).

Fisheries and Oceans Canada imposes a licence condition on the scallop fishery that requires the offshore fleet to use a vessel monitoring system, in order to verify all scallop landings. Monitoring is done through independent third parties known as Dockside Monitoring Companies (DMC). Briefly, licence holders fund a port-side sampling program in which DMC observers monitor the catch of each fishing trip for meat weight and count. Information from the port-side sampling program is shared among licence holders and reported to DFO. The fishing season for the scallop fishery in SFA 27 is open year round subject to the TAC. The annual TAC limits set for SFA 27 and its two sub-management units from 1998 to 2008 are listed in Table 4-1.

Table 4-1. Scallop fishery annual Total Allowable Catch limits (t) from 1998 to 2008 set for Scallop Fishing Area 27 and its sub-management units Georges Bank A and Georges Bank B.

Year	Scallop Fishing Area 27 (t)	Georges Bank A Sub-management Unit (t)	Georges Bank B Sub-management Unit (t)
1998	4000	3200	800
1999	3700	2500	1200
2000	6800	6200	600
2001	6900	6500	400
2002	6700	6500	200
2003	6200	6000	200
2004	3700	3500	200
2005	2700	2500	200
2006	4200	4000	200
2007	4400	4000	400
2008	5900	5500	400

4.2.1.2 Lobster and Crab Fisheries

The Canadian offshore lobster fishery began in 1972. In the 1970s and 1980s, lobster from Georges Bank accounted for 30-40% of the annual offshore lobster landings in the DFO Maritimes Region (Figure 4-4). This, however, declined to 15-18% by the mid-1990s, as fishing vessels began to focus their effort on the smaller, valuable, and more easily fished lobster west of Browns Bank. Crab landings in proximity of the moratorium area (excluding snow crab) also contribute a significant portion of the total crab landings observed in the DFO Maritimes Region (Figure 4-5). Jonah crab is the primary species caught in the area. It is managed under the same plan and advisory committee as lobster. The lobster and crab fisheries in the vicinity of the moratorium area consist of 8 active licences (i.e. each of the 8 licence holders hold a separate lobster and crab licence). Both fisheries are fished by one fleet pursuant to separate active licences, traps, and fishing trips.

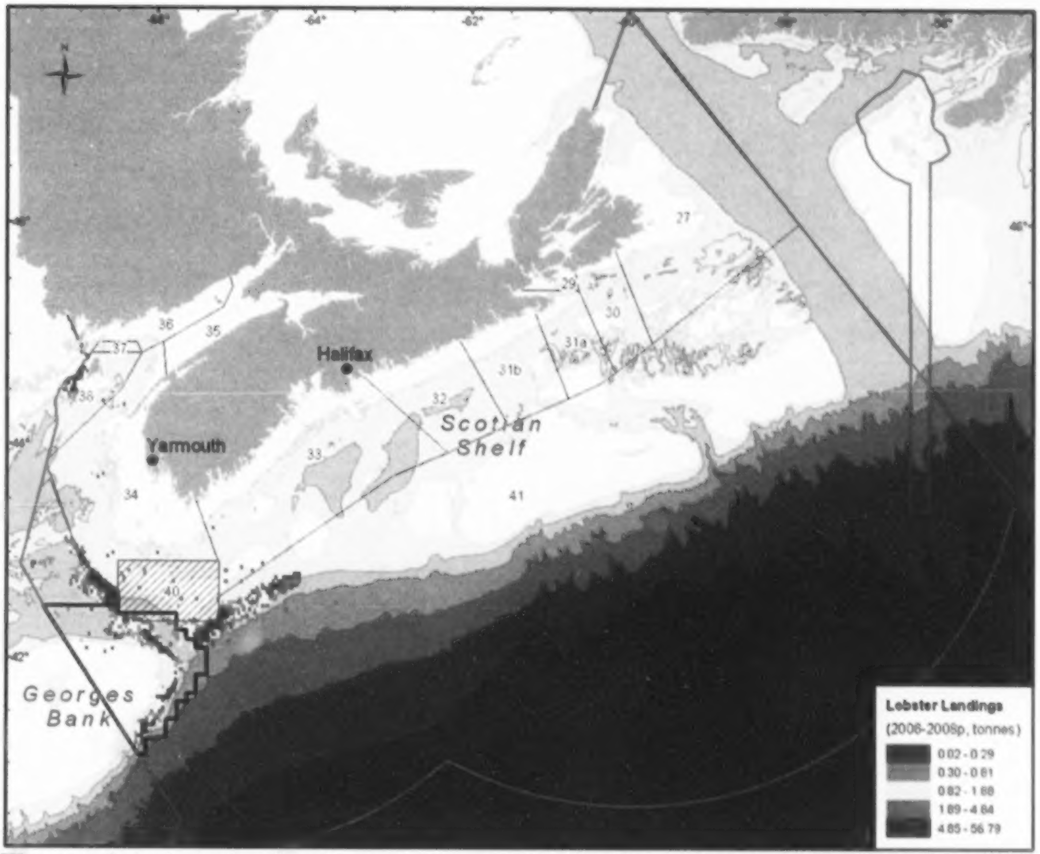

N
-66°
-64°
-62°
-60°
-58°
-56°
46°
44°
42°
27
29
30
31a
31b
32
33
34
35
36
37
38
40
41
Halifax
Yarmouth
Scotian Shelf
Georges Bank
Lobster Landings
(2006-2008p, tonnes)
0.02 - 0.29
0.30 - 0.81
0.82 - 1.88
1.89 - 4.84
4.85 - 56.79

Figure 4-4. Lobster landings in the DFO Maritimes Region from 2006-2008p. The 'p' refers to preliminary data for 2008. The purple lines represent the Lobster Fishing Areas.

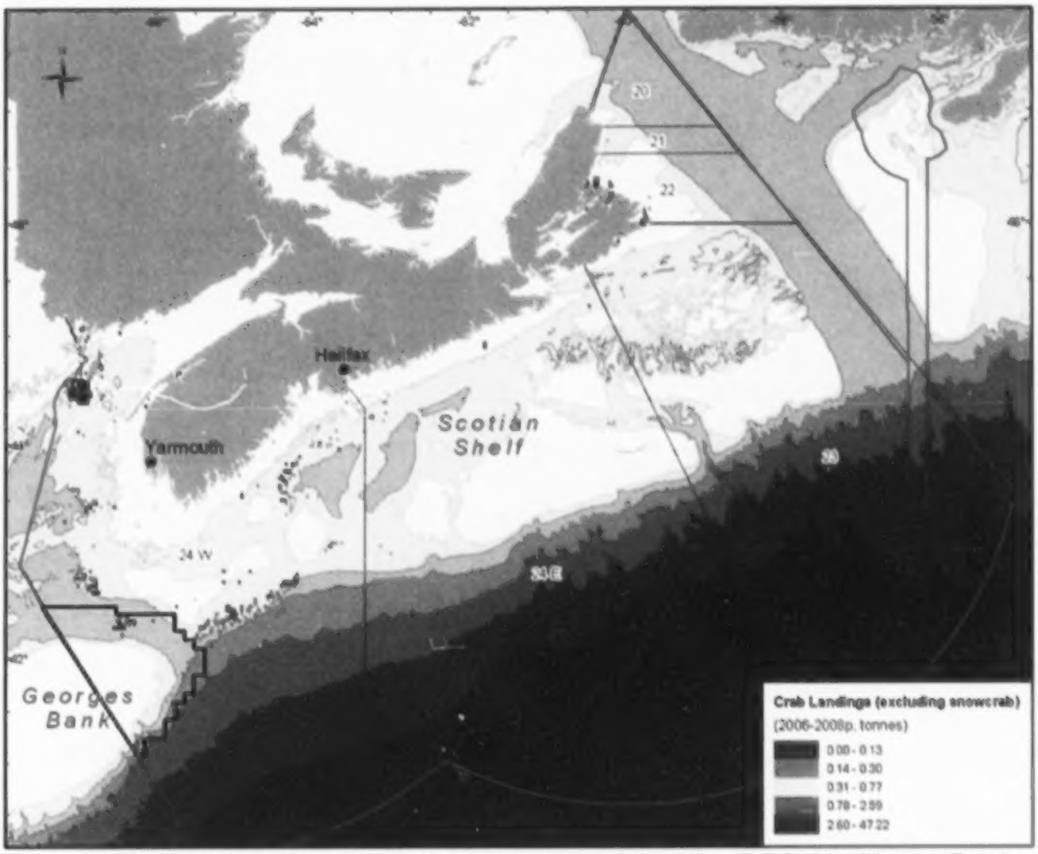

20
21
22
Halifax
Yarmouth
Scotian Shelf
24 W
Georges Bank
Crab Landings (excluding snowcrab)
(2006-2008p, tonnes)
0.00 - 0.13
0.14 - 0.30
0.31 - 0.77
0.78 - 2.59
2.60 - 47.22

Figure 4-5. Crab landings (excluding snow crab) in the DFO Maritimes Region from 2006-2008p. The 'p' refers to preliminary data for 2008. The purple lines represent the Crab Fishing Areas.

The fishing fleet consists of vessels that range from 17 to 43 m in length. The crew sizes vary from six to nine individuals. The vessels are located throughout ports in Shelburne and Lockeport of southwest Nova Scotia. Typically, crews receive approximately 40% of the total landed value of lobster and crab that they catch. A fishing trip is usually 4-5 days in length, although larger vessels operated by major licence holders are capable of fishing for much longer periods of time. The larger vessels are equipped with specialized storage facilities that can keep lobster and crab alive for extended periods, while maintaining the quality of the product.

The lobster and crab fisheries have been historically fished with traps and trawls, although the use of trawls has been significantly reduced in recent years. There is no limit on the number of traps that may be set per licence. Traps, however, must be tagged with DFO approved tags, which are noted on the fishing licence. The mesh size and/or escape mechanisms of traps (depending on which option receives DFO approval) are designed to allow undersized lobster and crab to escape a trap. In addition, the traps must have bio-degradable exit points that facilitate the release of caught individuals in the event of lost traps.

The lobster fishery in proximity of the moratorium area occurs in Lobster Fishing Area (LFA) 41. It extends from the Hague Line on Georges Bank to the Laurentian Channel of the eastern Scotian Shelf. The crab fishery in proximity of the moratorium area occurs in Crab Fishing Area (CFA) 24W. In general, commercial fishing for lobster and crab in the area occurs on five major grounds: 1) the Georges Bank outer shelf and upper slope; 2) Georges Basin; 3) Crowell Basin; 4) the Southeast Browns Bank outer shelf and upper slope east of the Northeast Channel; and 5) West Browns Bank. The lobster and crab fisheries of Georges Bank are concentrated along the outer shelf edge and upper slope, including parts of the Northeast Channel (Figures 4-4 and 4-5).

The lobster and crab fisheries are managed using four primary controls. First, the fisheries in LFA 41 and CFA 24W are subject to an annual TAC of 720 t for lobster and 720 t for crab, respectively. Second, a minimum carapace length of 82.5 mm is imposed for lobster (male and female) and minimum carapace width of 130 mm is imposed for male crab. Third, the number of issued fishery licences is restricted to eight licences per fishery. Last, a closure area is used to manage the lobster fishery (i.e. LFA 40 – see Figure 4-4). In 1979, LFA 40 was established on Browns Bank in an effort to protect an important brood stock of lobster in the area (Figure 4-4). The fishery season for lobster and crab is open year round subject to the TAC.

4.2.2 Groundfish Fisheries

The groundfish fisheries of Georges Bank have been in operation since the late-1700s. Since 1977, only Canada and the United States have had directed fisheries on the Bank and, with the establishment of the Hague Line in 1984, each country has been relegated to fishing its respective side of the line. The primary groundfish species caught in the moratorium area include cod, haddock, and yellowtail flounder. In Canada, several fishing fleets have access to groundfish resources on Georges Bank, with 700 active licences currently issued. There is no overall fishing vessel length restriction on Georges Bank and, as a result, vessels vary in size with some exceeding 30 m in length. The moratorium area is very important to the groundfish fisheries of the region (Figure 4-6).

The groundfish fisheries in proximity of the moratorium area occur in NAFO 5ZE. In recent years, Canada's groundfish fisheries have been conducted using mobile gear such as otter trawls and, to a lesser extent, longline vessels. Catches are also subject to TAC limits set for specific groundfish species fished in NAFO 5ZE. Due to differing abundances of cod and haddock, the cod TAC is usually reached before the haddock TAC. To selectively catch haddock, the mobile gear fleets use a horizontal separator panel that allows cod to escape, while retaining haddock in the upper portion of the trawl. In general, the selective mobile gear exhibits catch rates of haddock that are 100 times greater than cod, while the longline vessels average haddock catch rates that are only 3 times greater than cod. Groundfish is caught throughout the moratorium area, with the catch intensity decreasing towards the shelf break (Figure 4-6).

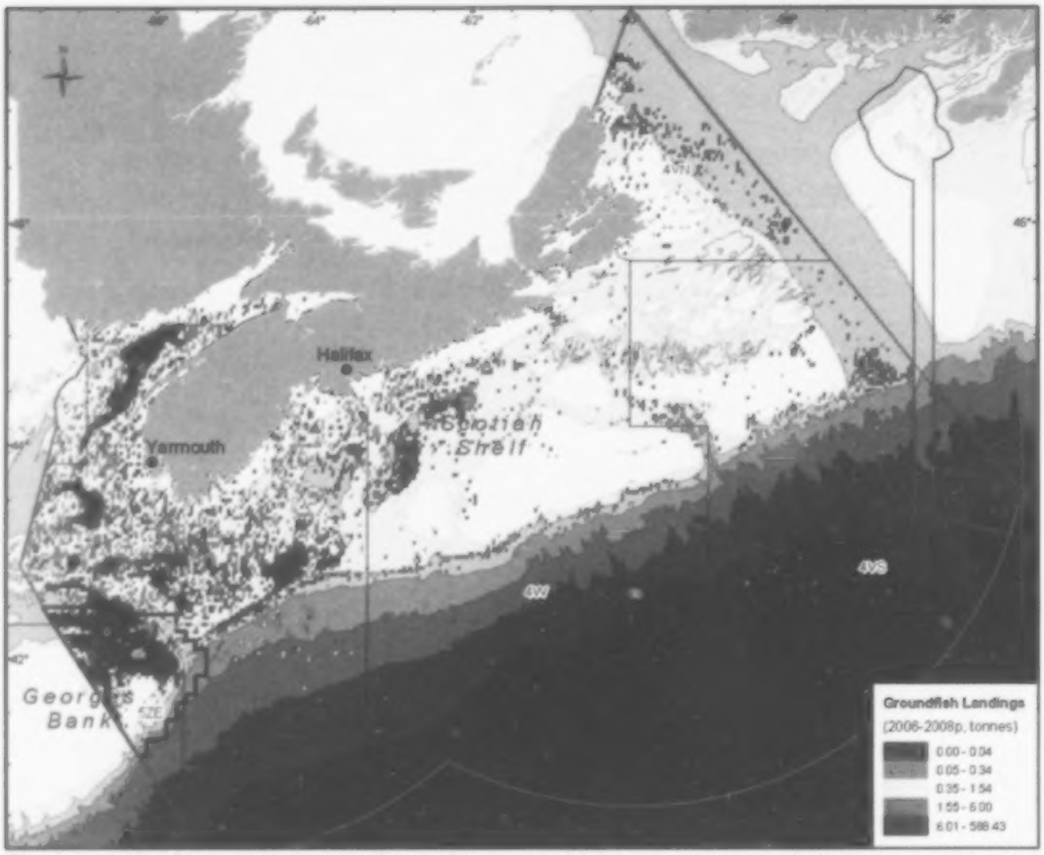


Figure 4-6. Groundfish landings (cod, haddock, and yellowtail flounder) in the DFO Maritimes Region from 2006-2008p. The 'p' refers to preliminary data for 2008. The purple lines represent the Northwest Atlantic Fishery Areas.

Groundfish species on Georges Bank are a transboundary fishery resource and are subject to cooperative management by Canada and the United States. The joint Canada-United States Transboundary Resources Assessment Committee (TRAC) has reviewed stock assessments and projections since 1998, in support of coordinated management activities of the shared fishery resources that migrate across the maritime boundary of Georges Bank and in the Gulf of Maine region. In 2000, the Transboundary Management Guidance Committee (TMGC) formed following an agreement on the consistent management of cod, haddock, and yellowtail flounder of eastern Georges Bank, which placed increased demands on the TRAC process. Guidance from TMGC is used to advise both Canadian and American decision makers on the status of transboundary fishery resources, as well as potential negative consequences of policy choices. Guidance from TMGC is used to inform the management of transboundary fishery resources, although each country retains the authority to manage the resources in its jurisdiction.

The groundfish fisheries of NAFO 5ZE are managed using two primary controls. First, the fisheries are subject to annual, species-specific TACs. Second, both Canada and the United States impose mesh size regulations, in order to limit the number of undersized fish that are captured. Over the past decade, the TAC for cod available to Canadian fishers has ranged from 700-2100 t (Figure 4-7). The highest observed TAC of 2100 t occurred in 2001. The TAC remained relatively constant from 2000 to 2009, with the average TAC being 1340 t. The TAC for haddock has seen a considerable increase over the past decade (Figure 4-7). From 2000 to 2005, the TAC increased from 5400-15,400 t. There was a slight decline from 2006 to 2007, although the TAC again increased reaching a decadal high of 18,900 t in 2009. Last, the TAC for yellowtail flounder has ranged from 400-3400 t over the past decade, with the lowest TACs observed from 2007 to 2009 (Figure 4-7).

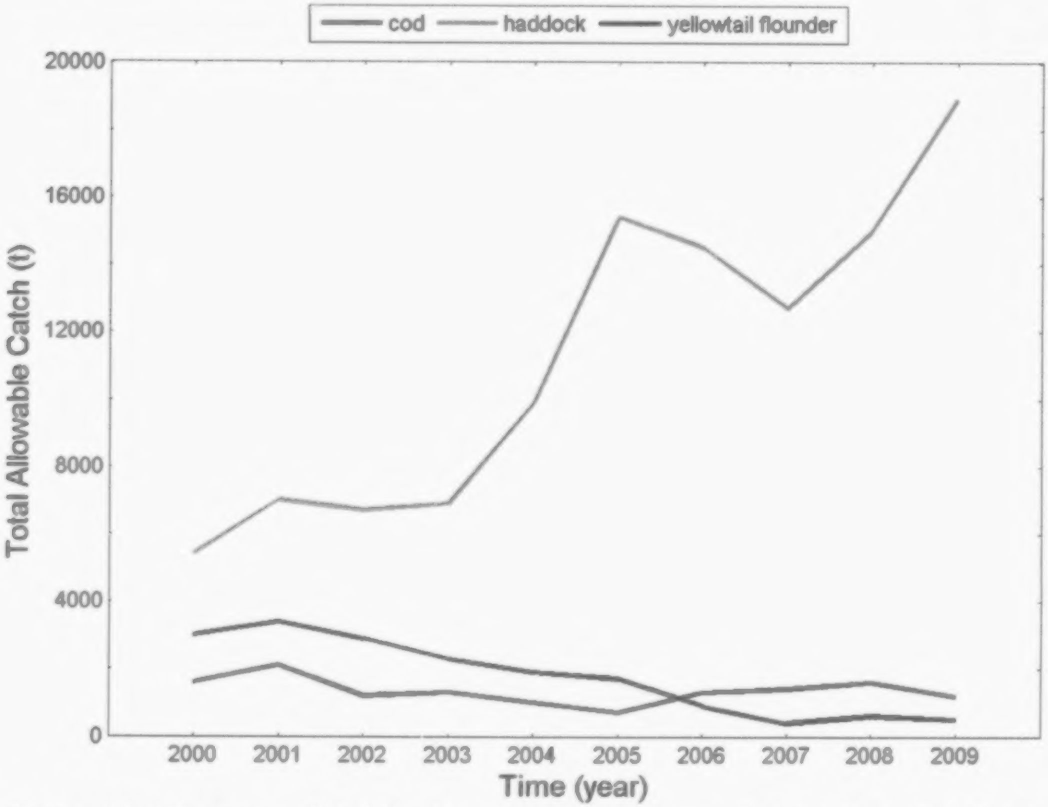


Figure 4-7. The groundfish fisheries of NAFO 5ZE annual Total Allowable Catch limits (t) for cod (red line), haddock (green line), and yellowtail flounder (blue line) from 1998 to 2008.

The groundfish fisheries are subject to a dockside monitoring program, which verifies all landings through independent third party verification (i.e. DMC). At sea observer verification levels often vary by year and season, ranging from 25-100% coverage. For the cod fishery, at-sea observers monitor approximately 38% of the catch by weight caught by the mobile gear fleet and 21% catch by weight caught by the fixed gear fleet. In 2008, 38% of the total haddock catch by weight was observed at sea. Discarding and misreporting of haddock by the fishing fleet have remained negligible since 1992. The cod, haddock, and yellowtail flounder fisheries in NAFO 5ZE are open most of the year, with the exception of a regulated closure from March 1 to May 31. The closure is used to reduce the impact on spawning groundfish. The annual TAC limits set for the cod, haddock, and yellowtail flounder fisheries in NAFO 5ZE from 1998 to 2008 are listed in Table 4-2.

Table 4-2. The groundfish fisheries annual Total Allowable Catch limits (t) for cod, haddock, and yellowtail flounder from 1998 to 2008.

Year	cod (t)	haddock (t)	yellowtail flounder (t)
2000	1600	5400	3000
2001	2100	7000	3400
2002	1200	6700	2900
2003	1300	6900	2300
2004	1000	9900	1900
2005	700	15400	1700
2006	1300	14500	900
2007	1400	12700	400
2008	1600	15000	600
2009	1200	18900	500

4.2.3 Pelagic Fisheries

The pelagics fisheries operating in the moratorium area include swordfish, tuna, herring, and other pelagic species such as mahi mahi and shark. Currently, there are 1006 active commercial pelagic fishing licences issued for the area. The following sections describe in more detail the pelagics fisheries operating in the moratorium area.

4.2.3.1 Swordfish and Tuna (Yellowfin, Bigeye, and Albacore) Harpoon and Longline Fisheries

The Atlantic swordfish fishery began in the late 1880s, as harpoon sailing vessels fished swordfish throughout Atlantic Canada and along annual swordfish migration routes off the eastern United States. The North Atlantic swordfish stocks fall under the stewardship of the International Commission for the Conservation of Atlantic Tunas (ICCAT), which was established in 1969. In the early 1960s, the Atlantic swordfish fishery moved from a harpoon fishery to primarily a longline fishery, although harpoons are still used today. Tuna fisheries are integated with the longline swordfish fishery due to the nature of the fishing gear.

The harpoon fishery is fished in surface waters. Briefly, harpoons are poles with a detachable barbed spear tip. The harpoon tip is attached to a line with a buoy at the opposite end, while a retaining line is attached to the butt end of the harpoon shaft. The harpoon is positioned at the front of the vessel, often from the end of a forward extension called a stand. The vessel steams behind a fish and the harpoon is thrown and embedded into its flesh. The tip of the harpoon is then pulled from the shaft as the fish swims away. The harpoon shaft is retrieved while the fish tows the harpoon tip, line, and buoy. The gear is tracked by following the float as the fish swims to exhaustion.

In contrast, longline gear is fished in the water column and is suspended from floats at a desired depth. The mainline of pelagic fishing gear consists of monofilament backline (i.e. 800 pound Test), which extends up to 64 km in length behind the fishing vessel. Pelagic gangions range from 2-10 m in length and are spaced 40-100 m apart. The longline gear is typically marked with highflyers and radio beacons and, in addition to hooks, lines may also carry hookless teasers. The longline fishing fleet may also use trolling gear, which consists of multiple lines towed from outrigger poles, as well as harpoon gear.

The Canadian swordfish longline fishery operates from Georges Bank to the eastern edge of the Grand Banks when swordfish migrate into Canadian waters during summer and fall. More than 25% of Canada's annual landings occur in the Georges Bank moratorium area (Figure 4-8). In the offshore of Nova Scotia, the swordfish fishing effort generally moves from the southwest to northeast on the Scotian Shelf and back along the shelf break, following the swordfish movements associated with the seasonal warming of surface waters.

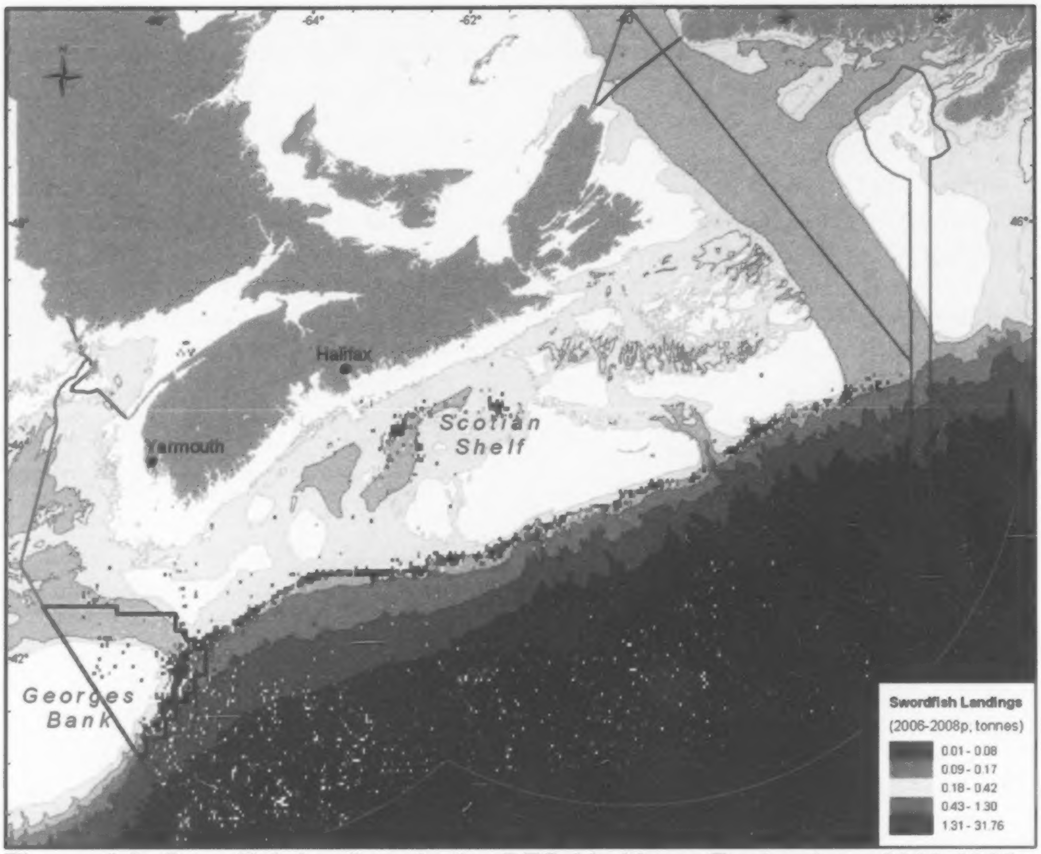

-64°
-62°
-60°
-58°
46°
44°
42°
Halifax
Yarmouth
Scotian Shelf
Georges Bank
Swordfish Landings
(2006-2008p, tonnes)
0.01 - 0.08
0.09 - 0.17
0.18 - 0.42
0.43 - 1.30
1.31 - 31.76

Figure 4-8. Swordfish landings in the DFO Maritimes Region from 2006-2008p. The 'p' refers to preliminary data for 2008. The purple lines represent the outer fishing boundaries for the region.

The geographic and seasonal catch patterns of tuna fish follow a similar pattern to swordfish (Figure 4-9). Yellowfin tuna, bigeye tuna, and albacore are typically caught along the edge of Georges Bank from June to October and in more western areas (i.e. west of 60-degrees West longitude) from June to September. Bigeye tuna are the most abundant tuna species captured in the longline fishery. The catch abundance of bigeye tuna is generally highest from July to August. The tuna catch in more eastern regions of the Scotian Shelf and shelf break are typically lower and more variable.

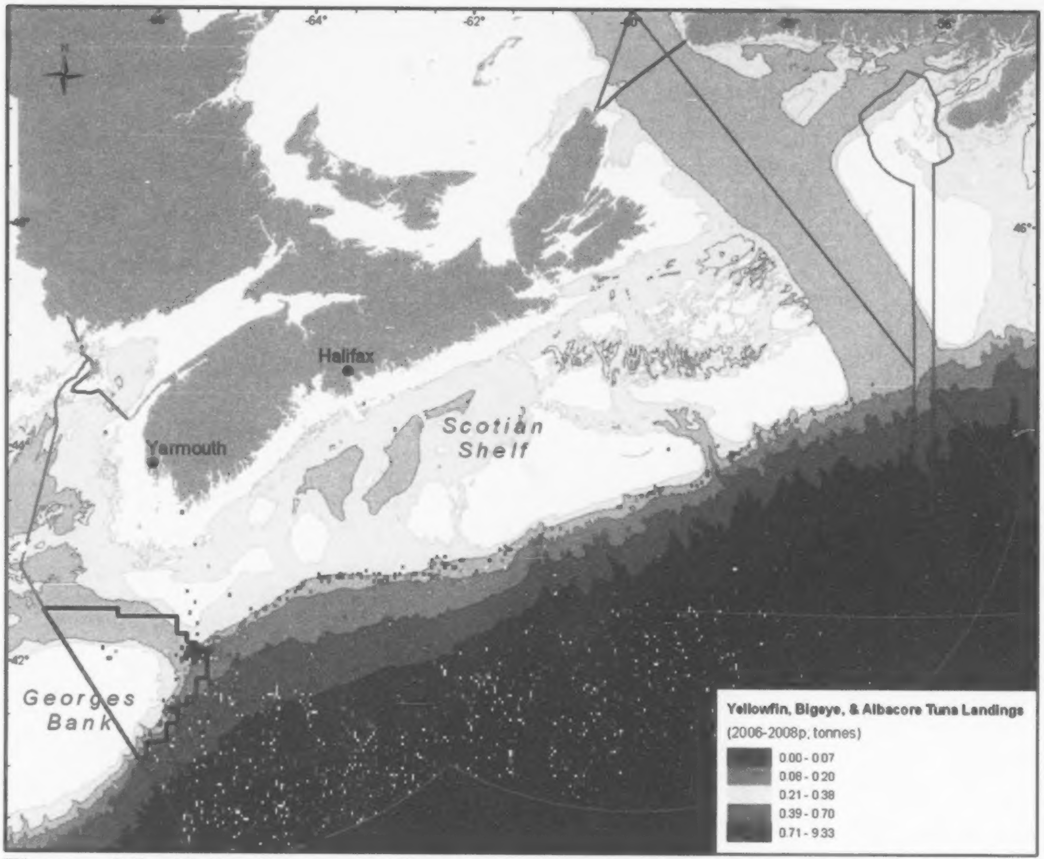

-64°
-62°
-60°
-58°
46°
44°
42°
N
Halifax
Yarmouth
Scotian Shelf
Georges Bank
Yellowfin, Bigeye, & Albacore Tuna Landings
(2006-2008p, tonnes)
0.00 - 0.07
0.08 - 0.20
0.21 - 0.38
0.39 - 0.70
0.71 - 9.33

Figure 4-9. Yellowfin tuna, bigeye tuna, and albacore landings in the DFO Maritimes Region from 2006-2008p. The 'p' refers to preliminary data for 2008. The purple lines represent the outer fishing boundaries for the region.

In 1991, ICCAT management measures were put in place for the North Atlantic swordfish fishery, in an effort for countries to reduce their catch of swordfish by 15% at 1988 levels. Minimum catch sizes were also put into place at that time. These measures led Canada to reduce its TAC, as well as to introduce domestic measures to limit the harvesting of undersized swordfish. The North Atlantic swordfish stock is now considered to be 'rebuilt' by ICCAT, although the TAC remains lower than historic catch levels. With annual swordfish TAC levels declining in recent years, the longline fleet has redirected its fishing towards tuna species such as yellowfin tuna, bigeye tuna, and albacore.

The swordfish and tuna fisheries are managed using an Integrated Fisheries Management Plan (IFMP). The Plan, which was developed as a result of allocations and other management measures set out by ICCAT, aims to ensure that Canada does not exceed its allocation in any given year. The ICCAT allocations contribute to the rebuilding and maintainence of the North Atlantic swordfish stock at biomass levels that would support a level of fishing equivalent to the maximum sustainable yield. To participate in the fisheries, each fishery association, group of fishers, or individual licence holder that harvests as part of the IFMP must submit a Conservation Harvesting Plan (CHP) for approval by DFO. A CHP outlines how a group or individual proposes to fish in line with the requirements of the respective fleet sector plan. Any new CHPs or substantial changes to existing CHPs must undergo a review by DFO prior to approval.

Following approval of a CHP, licence conditions are issued to those harvesters covered by the plan. Conservation Harvesting Plans must, at a minimum, specify arrangements for at-sea monitoring where required by a fleet sector plan, dockside monitoring of all landings, and how the group or individuals covered by the CHP will contribute to the enhanced scientific assessment of the stock, co-management initiatives (if applicable), and quota management. In addition to the IFMP and CHPs, the fisheries are managed using TACs and licences. In 2003, the Atlantic swordfish fishery TAC was 1463 t. It was reduced to 1348 t in 2004, where it has remained to date. For tuna species, Canada is currently subject to an annual TAC of 2100 t for bigeye tuna, 200 t for albacore (since 2005), while no TAC is currently in place for yellowfin tuna.

Canada limits the number of fishing licences that it issues. At present, only 1254 licences have been issued Atlantic-wide. Of these, 894 licences are located in the DFO Maritimes Region. Of the 1254 licences only 188 harpoon-only licences are active. The majority of active harpoon-only licence holders are represented by the Swordfish Harpoon Association located on the south shore of Nova Scotia. In contrast, there are a total of 77 active Pelagic longline licences (i.e. swordfish and tuna), of which 75 are currently located in the DFO Maritimes Region. Seventy-three of the 77 vessels licenced to fish swordfish and tuna are less than 20 m in length. Three of the remaining four vessels range from 20-30 m in length and one vessel is greater than 30 m in length.

There is not a significant bycatch associated with the harpoon fishery, although some wounded swordfish escape causing uncaught mortality. For the longline fishery, bycatch such as bluefin tuna, porbeagle shark, shortfin mako, blue fin shark, mahi mahi, and marlin may be retained by the fleet (Figure 4-10). Certain bycatch species encountered in the longline fishery, however, may not be retained including the loggerhead turtle and leatherback turtle, cutlass fishes, longnose lancetfish, sunfish, and pelagic stingrays. These species must be released or discarded at sea. In practice, the pelagic longline fleet has adopted a number of mitigation measures to minimize bycatch, especially for sea turtles. For example, circle hooks are now generally used and are thought to reduce accidental hooking mortality compared to j-hooks, while all holders of active licences have been trained and carry dehooking and line cutting equipment that can be used to release vulnerable species including at risk aquatic species. In addition, the fleet has created a Code of Conduct for the mitigation of sea turtle interactions, which must be followed as a condition of licence. The swordfish and tuna fisheries operate throughout the year, with TACs renewed annually on the first of April.

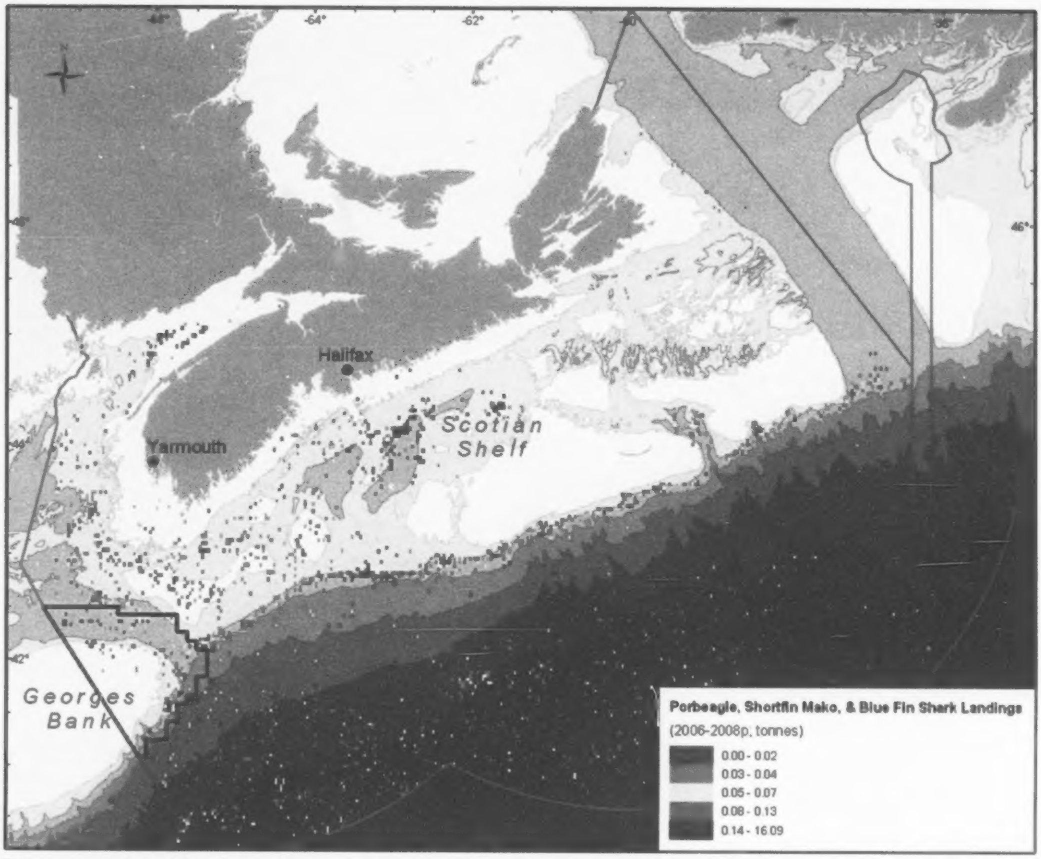

-64°
-62°
-60°
-58°
46°
44°
42°
Halifax
Yarmouth
Scotian Shelf
Georges Bank
Porbeagle, Shortfin Mako, & Blue Fin Shark Landings
(2006-2008p, tonnes)
0.00 - 0.02
0.03 - 0.04
0.05 - 0.07
0.08 - 0.13
0.14 - 16.09

Figure 4-10. Porbeagle shark, shortfin mako shark, and blue fin shark landings in the DFO Maritimes Region from 2006-2008p. The 'p' refers to preliminary data for 2008.

4.2.3.2 Blue Fin Tuna Tended Line and Rod and Reel Fishery

The bluefin tuna fishery operates in several locations off the Atlantic coast of Canada when bluefin tunas migrate into Canadian waters from July to November. The fishery in proximity of the moratorium area primarily occurs on the Bank's northern flank and in the Northeast Channel between Browns Bank and Georges Bank in an area known as the Hell Hole (Figure 4-11). Bluefin tuna form distinct aggregations in Canadian waters that can vary from one year to the next. The Hell Hole aggregation has supported a significant bluefin tuna fishery since the fishery's establishment in 1988. Monthly catches in the Hell Hole have shown an increasing trend from July to September, with the highest catches occurring from August to September.

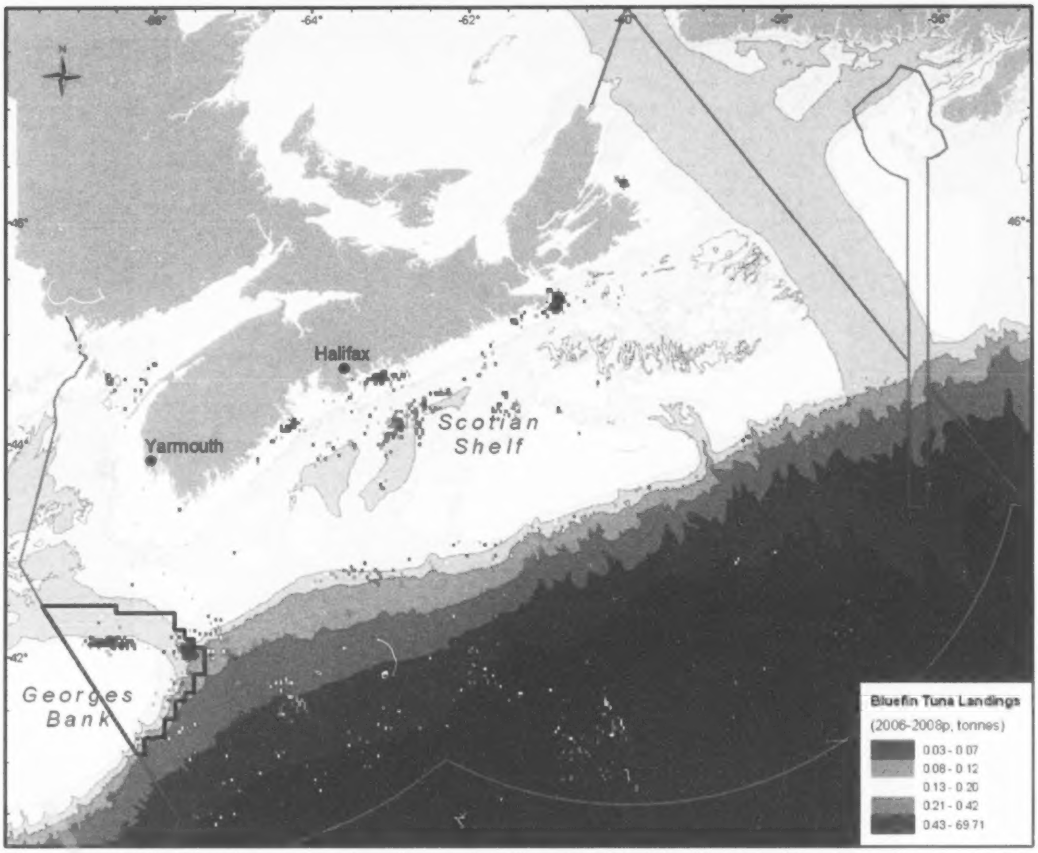


Figure 4-11 Bluefin tuna landings in the DFO Maritimes Region from 2006-2008p. The ‘p’ refers to preliminary data for 2008.

Bluefin tuna fishing is undertaken using tended lines and rod and reel, although the fishery in the area primarily uses tended line gear. Tended lines consist of a hook and line tied to a vessel. Once a fish is hooked, the line (which is attached to a buoy) is set free allowing the tuna to swim to exhaustion. It is then retrieved. A maximum of four lines may be in the water at any given time, although only up to two of these can be tended lines. Bluefin tuna licence holders may also use an electric harpoon, which is a barbed lance or spear that is connected to an electrical device on board the vessel. It is capable of shocking and killing the tuna instantly. Bluefin tuna licence holders are permitted to retain bycatch of yellowfin tuna, bigeye tuna, albacore, and various sharks.

Given the migratory nature of bluefin tuna, stocks throughout the Atlantic Ocean fall under the jurisdiction of ICCAT. Beyond ICCAT management measures, the bluefin tuna tended line and rod and reel fishery in Canada is managed using an IFMP. Quotas are established annually and any unused bluefin tuna allocation may be carried forward to the following year. Bluefin tuna fleets must submit a CHP in advance of each fishing season. In addition to the IFMP and CHPs, the fishery is managed using a TAC and licences. Annually, Canada receives a TAC of approximately 24% of the overall western Atlantic Ocean bluefin tuna catch set by ICCAT.

The bluefin tuna fishing fleet of southwest Nova Scotia receives the majority of Canada's allocation, which is approximately 22% of the Atlantic quota set by ICAAT. Presently, there are 32 active tended line and rod and reel licences for bluefin tuna in the DFO Maritimes Region. Holders of active licences can fish in the moratorium area. In addition, bluefin tuna licence holders from other DFO Regions (e.g. Gulf Region of New Brunswick, Gulf Region of Nova Scotia, and Newfoundland and Labrador) can also fish in the moratorium area if they meet the requirements of the fishery (e.g. submit a CHP for approval by DFO). The bluefin tuna fishing season typically commences in July and concludes in mid- to late-November. Most fleets focus their fishing effort based on market conditions, in order to maximize the value of the fishery.

4.2.3.3 Herring Fishery

Georges Bank once supported the largest herring fishery in the western Atlantic Ocean. In the late 1960's and early 1970's, reported annual commercial landings from Georges Bank exceeded 200,000 t. The fishery peaked in 1968, with reported landings exceeding 374,000 t. Actual landings are believed to have been much greater. The herring fishery on Georges Bank began in 1961 when the former Soviet Union landed 68,000 t of fish. From 1961 to 1965, the Soviet Union dominated the fishery with annual catches ranging from 38,000 to 151,000 t. The fishery rapidly expanded in 1967, as Poland and the German Democratic Republic entered the fishery. Over the next 9 years, vessels from 12 countries harvested herring from the Georges Bank area, including Canada and the United States (which by reported landings were minor players). No directed fishery for herring occurred on Georges Bank between 1978 and 1993.

The herring fishery in proximity of the moratorium area occurs in Herring Fishing Area (HFA) 20. The fishery on Georges Bank occurs primarily on its northern outer edge (Figure 4-12). It is conducted by mid-water trawl and by-catch is minimal. The fishery is managed using an IFMP. The plan outlines specific management measures for the fishery on Georges Bank beyond the annual TAC of 20,000 t for HFA 20 that was set in 2004. Management measures include: 1) mobile gear must operate with Conditions of Licence that requires reporting and monitoring of landings in accordance with the provisions of an industry-funded Dockside Monitoring Program; 2) vessels operating in the Georges Bank area must accommodate scientific and technical personnel and participate in tagging efforts, fish surveys, and the provision of fish samples upon direction by DFO; 3) vessels must carry fishery observers upon direction by DFO at a cost to the industry; and 4) no foreign fishing vessels are permitted to fish on Georges Bank. Presently, there are 45 mobile gear licences issued for the fishing of herring on Georges Bank. In recent years, most herring licences in HFA 20 have been

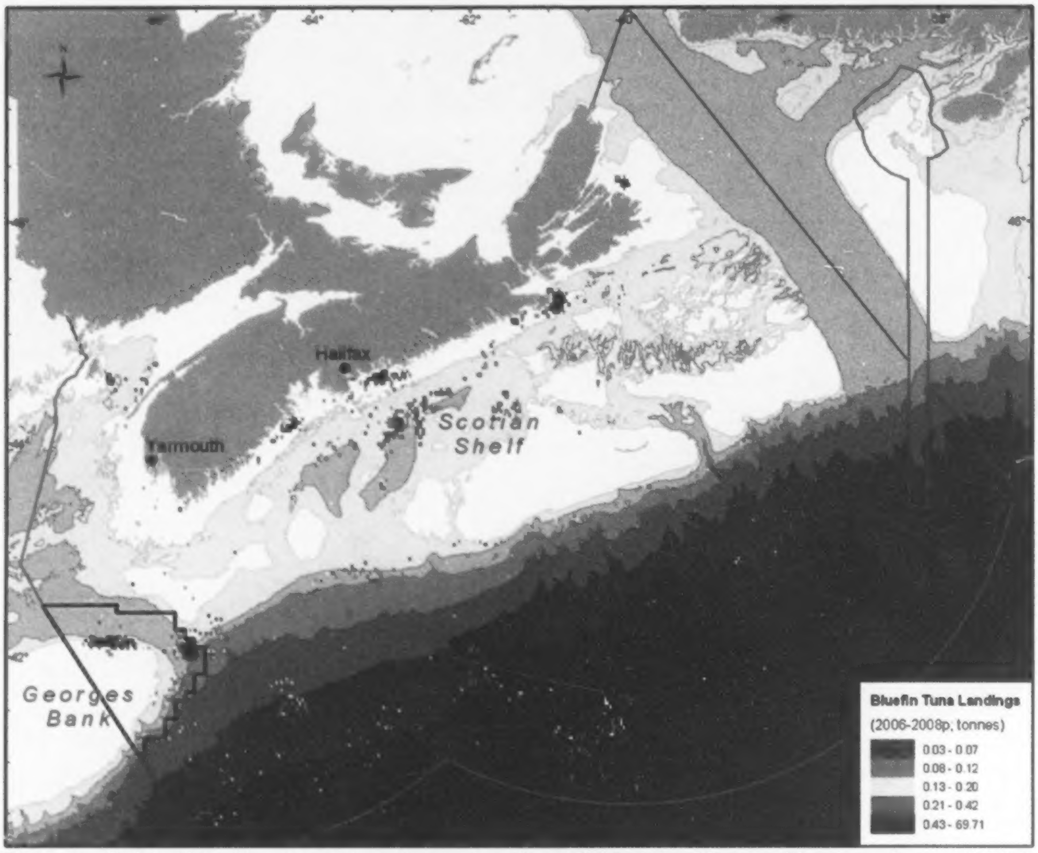


Figure 4-11 Bluefin tuna landings in the DFO Maritimes Region from 2006-2008p. The 'p' refers to preliminary data for 2008.

Bluefin tuna fishing is undertaken using tended lines and rod and reel, although the fishery in the area primarily uses tended line gear. Tended lines consist of a hook and line tied to a vessel. Once a fish is hooked, the line (which is attached to a buoy) is set free allowing the tuna to swim to exhaustion. It is then retrieved. A maximum of four lines may be in the water at any given time, although only up to two of these can be tended lines. Bluefin tuna licence holders may also use an electric harpoon, which is a barbed lance or spear that is connected to an electrical device on board the vessel. It is capable of shocking and killing the tuna instantly. Bluefin tuna licence holders are permitted to retain bycatch of yellowfin tuna, bigeye tuna, albacore, and various sharks.

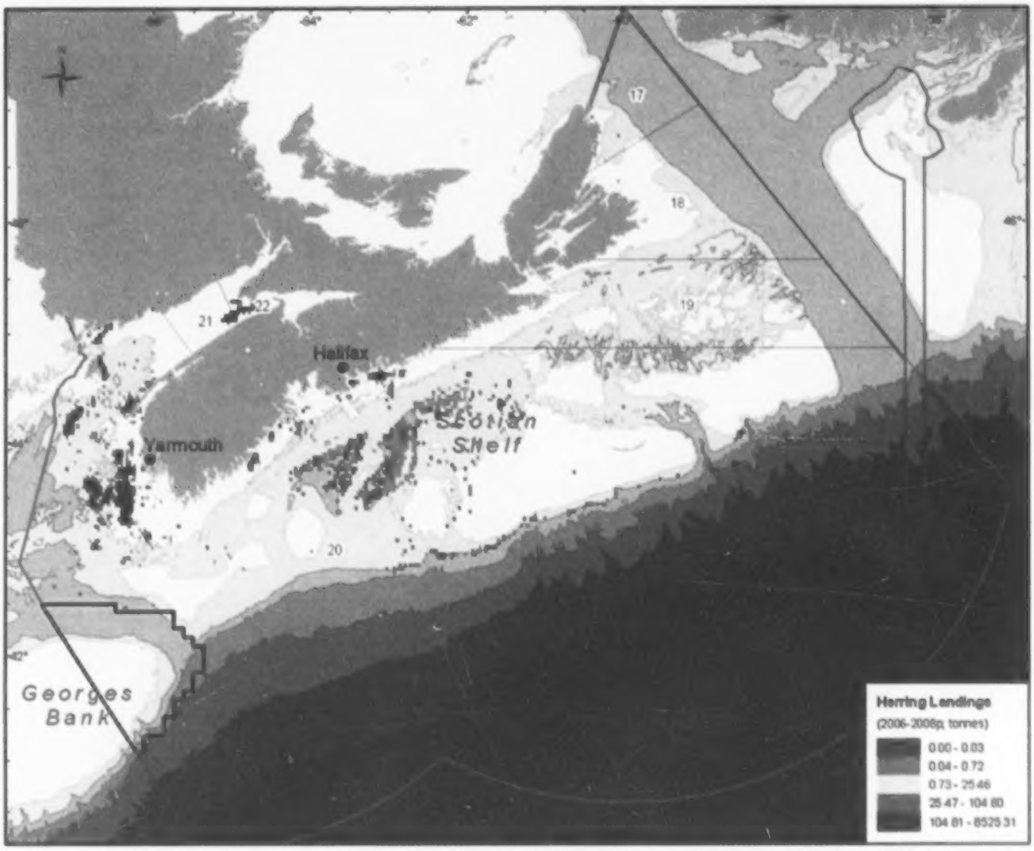
Given the migratory nature of bluefin tuna, stocks throughout the Atlantic Ocean fall under the jurisdiction of ICCAT. Beyond ICCAT management measures, the bluefin tuna tended line and rod and reel fishery in Canada is managed using an IFMP. Quotas are established annually and any unused bluefin tuna allocation may be carried forward to the following year. Bluefin tuna fleets must submit a CHP in advance of each fishing season. In addition to the IFMP and CHPs, the fishery is managed using a TAC and licences. Annually, Canada receives a TAC of approximately 24% of the overall western Atlantic Ocean bluefin tuna catch set by ICCAT.

The bluefin tuna fishing fleet of southwest Nova Scotia receives the majority of Canada's allocation, which is approximately 22% of the Atlantic quota set by ICAAT. Presently, there are 32 active tended line and rod and reel licences for bluefin tuna in the DFO Maritimes Region. Holders of active licences can fish in the moratorium area. In addition, bluefin tuna licence holders from other DFO Regions (e.g. Gulf Region of New Brunswick, Gulf Region of Nova Scotia, and Newfoundland and Labrador) can also fish in the moratorium area if they meet the requirements of the fishery (e.g. submit a CHP for approval by DFO). The bluefin tuna fishing season typically commences in July and concludes in mid- to late-November. Most fleets focus their fishing effort based on market conditions, in order to maximize the value of the fishery.

4.2.3.3 Herring Fishery

Georges Bank once supported the largest herring fishery in the western Atlantic Ocean. In the late 1960's and early 1970's, reported annual commercial landings from Georges Bank exceeded 200,000 t. The fishery peaked in 1968, with reported landings exceeding 374,000 t. Actual landings are believed to have been much greater. The herring fishery on Georges Bank began in 1961 when the former Soviet Union landed 68,000 t of fish. From 1961 to 1965, the Soviet Union dominated the fishery with annual catches ranging from 38,000 to 151,000 t. The fishery rapidly expanded in 1967, as Poland and the German Democratic Republic entered the fishery. Over the next 9 years, vessels from 12 countries harvested herring from the Georges Bank area, including Canada and the United States (which by reported landings were minor players). No directed fishery for herring occurred on Georges Bank between 1978 and 1993.

The herring fishery in proximity of the moratorium area occurs in Herring Fishing Area (HFA) 20. The fishery on Georges Bank occurs primarily on its northern outer edge (Figure 4-12). It is conducted by mid-water trawl and by-catch is minimal. The fishery is managed using an IFMP. The plan outlines specific management measures for the fishery on Georges Bank beyond the annual TAC of 20,000 t for HFA 20 that was set in 2004. Management measures include: 1) mobile gear must operate with Conditions of Licence that requires reporting and monitoring of landings in accordance with the provisions of an industry-funded Dockside Monitoring Program; 2) vessels operating in the Georges Bank area must accommodate scientific and technical personnel and participate in tagging efforts, fish surveys, and the provision of fish samples upon direction by DFO; 3) vessels must carry fishery observers upon direction by DFO at a cost to the industry; and 4) no foreign fishing vessels are permitted to fish on Georges Bank. Presently, there are 45 mobile gear licences issued for the fishing of herring on Georges Bank. In recent years, most herring licences in HFA 20 have been inactive, although the few harvesters with active licences remain competitive in the fishery. The herring fishery is open year round subject to the TAC.



17
18
19
20
21
22
Halifax
Yarmouth
Scotian Shelf
Georges Bank
Herring Landings
(2006-2008p, tonnes)
0.00 - 0.03
0.04 - 0.72
0.73 - 25.46
25.47 - 104.80
104.81 - 8525.31

Figure 4-12. Herring landings in the DFO Maritimes Region from 2006-2008p. The 'p' refers to preliminary data for 2008. The purple lines represent the outer fishing boundaries for the region.

4.3 OTHER OCEAN USERS

4.3.1 Offshore Petroleum

Offshore petroleum rights exist in the moratorium area. BP Canada Energy Company holds 14 exploratory permits and Chevron Canada Limited holds 40 permits in the moratorium area (Figure 4-13). In addition, several exploratory permits are also held adjacent to the moratorium area. These include 16 permits held by BP and five held by Chevron. Offshore petroleum rights in the moratorium area are held as exploratory permits issued between 1964 and 1971 under the Canada Oil and Gas Land Regulations. An exploratory permit would have had the same rights and privileges as an exploration licence (in accordance with the legislation).

The terms of these permits have been extended by a series of variation orders. Pursuant to the *Canada Oil and Gas Act*, permits in force on the date of proclamation of March 5, 1982, continued in force subject to certain provisions requiring the negotiation of exploration agreements. The *Canada Oil and Gas Act* provided that if an exploration agreement could not be negotiated in the required time period for any reason not attributable to the interest owner, the Minister (of Natural Resources Canada or Indian Affairs and Northern Development Canada (the name of the federal Department at the time) depending on the administrative responsibility of natural resources that fall under each Minister) was required to extend that period to allow for such negotiation in a reasonable time. Permits held in the Georges Bank moratorium area that were issued pursuant to the Canada Oil and Gas Land Regulations are considered 'frozen' due to the moratorium (i.e. terms extended and obligations postponed).

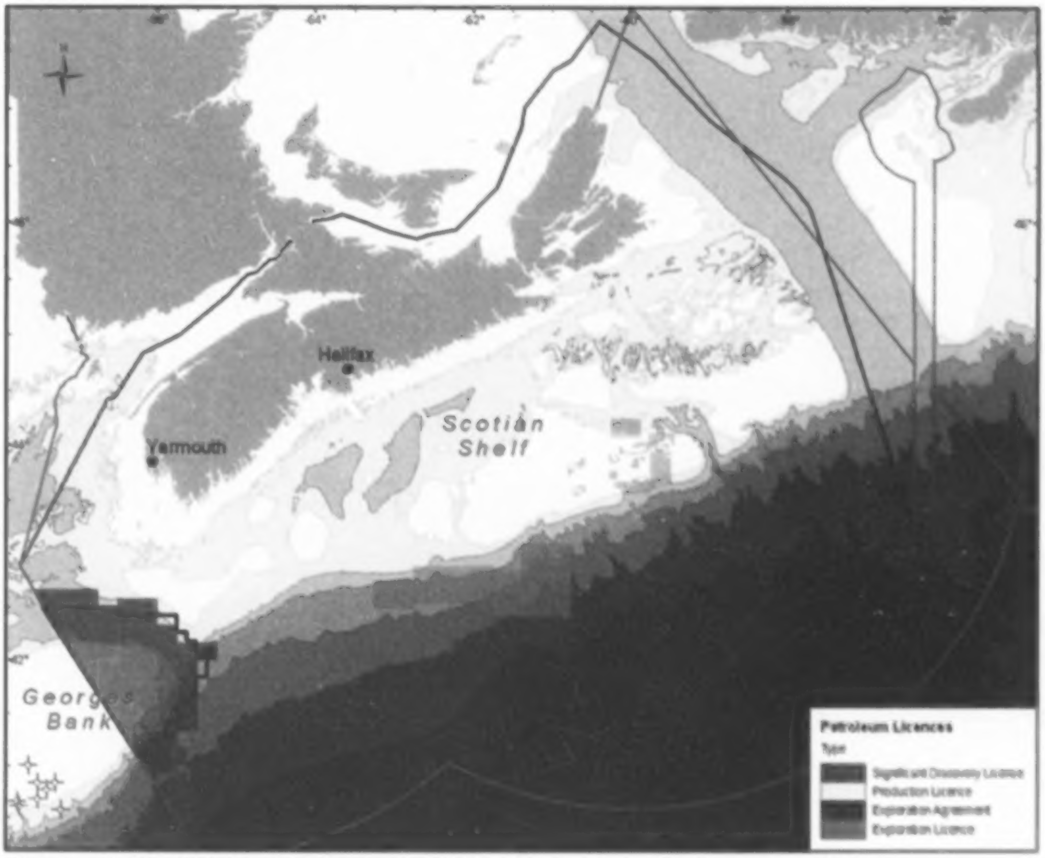

Halifax
Yarmouth
Scotian Shelf
Georges Bank
Petroleum Licences
Type
Significant Discovery Licence
Production Licence
Exploration Agreement
Exploration Licence

Figure 4-13. Offshore petroleum rights in the moratorium area (data courtesy of the Canada-Nova Scotia Offshore Petroleum Board). The coloured polygons represent various types of petroleum licences. The black circles with tick marks represent the locations of eight petroleum exploratory wells drilled on the U.S. portion of Georges Bank. The purple lines represent the jurisdictional boundary of the Canada-Nova Scotia Offshore Petroleum Board.

Before offshore petroleum exploration and development activities can commence on lands covered by a permit, the permit must be replaced by a negotiated exploration licence as provided in the legislation. Due to the moratorium, the time within which an exploration licence must be negotiated has been extended by the Canada-Nova Scotia Offshore Petroleum Board (the Board). The holder of an exploratory permit has the right to negotiate exploration licences for the exploratory permits. A licence holder has: the right to explore for, drill, and test for petroleum; the exclusive right to develop those portions of the offshore areas in order to produce petroleum; and the exclusive right, subject to compliance with the other provisions (e.g. best practice, environmental assessment, and environmental effects monitoring), to obtain a production licence.

The exploratory permits issued in the moratorium area are different from other exploration licences issued in the offshore of Nova Scotia, in that the exploratory permits were issued between 1964 and 1971 pursuant to regulations made in accordance with the *Territorial Lands Act*, the *Public Lands Grants Act*, and include an exploration agreement entered into under the Canada Oil and Gas Land Regulations. In contrast, exploration licences issued after July 21, 1988, are done so pursuant to the *Canada-Nova Scotia Offshore Petroleum Resources Accord Implementation Act*. The permits also differ in that obligations under an exploratory permit are suspended while a prohibition order is in force and there is a corresponding extension to the term of the permit.

The holders of exploratory permits in the moratorium area were required (on or before the first anniversary date of any such interest following March 5, 1982, or on or before six months following such date, whichever was later) to negotiate an exploration licence with the CNSOPB according to section 133 of the *Canada-Nova Scotia Offshore Petroleum Resources Accord Implementation Act*. Section 135 of the act also states that where an exploration licence is required to be negotiated, can not be negotiated within the period provided, for any reason not attributable to the interest owner, the Board shall extend that period to allow for such negotiation within a reasonable time.

Since converting the permits at the present time would result in the clock starting on the new exploration licences prior to any moratorium expiration, it may be argued that exploration licences can not be negotiated due to a reason not attributable to the interest owners and that therefore the time period must be extended. The obligation to negotiate exploration licences is on the permit holders. In the event of the removal of the prohibition order (i.e. the moratorium), permit holders must negotiate exploration licences (as per the legislation) in the same time period specified in the *Canada Oil and Gas Act* (i.e. 6 months). Failure to comply would result in deemed surrender of the speculative petroleum interest and its return to the Crown. In the event that the moratorium expires, it would be reasonable to assume that the Board's 'Guideline on the Issuance of Exploration Licences' would form the basis of any negotiations for exploration licences currently held in the moratorium area.

4.3.2 Maritime Transportation

Significant commercial shipping activity occurs across and in the vicinity of Georges Bank. Figure 4-14 exhibits typical international shipping routes through the region. In general, the main shipping routes include: trans-Atlantic shipping between Europe and the eastern United States; coastal shipping between eastern Canada and the eastern United States; and shipping between South America, the Caribbean, and eastern Canada. The highest levels of trans-Atlantic traffic through the moratorium area occur in its southern portion. The main routes used between ports in the northeastern United States (in the Gulf of Maine) and eastern Canada are located north of the Bank.

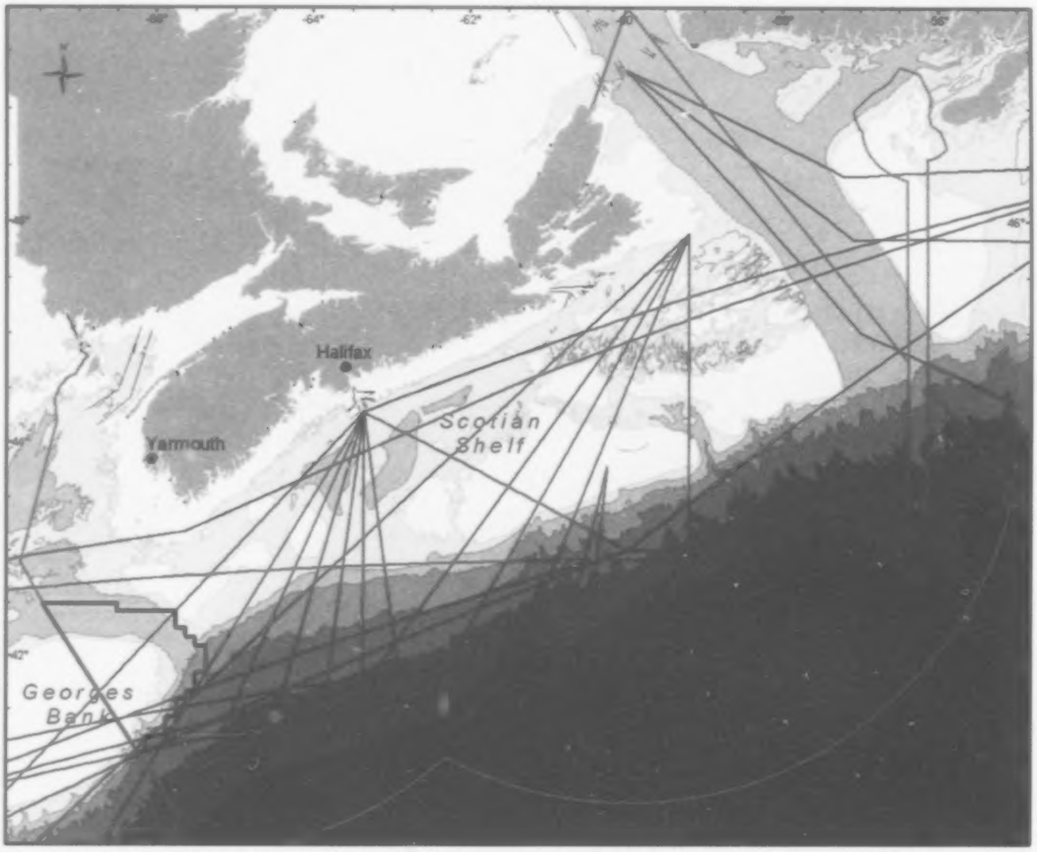


Figure 4-14. Primary maritime traffic routes in the vicinity of the moratorium area.

Figure 4-15 exhibits inbound shipping intensity in 2000, as an illustration of typical Canada-US traffic in the area. Commercial shipping traffic in the region generally consists of tankers and cargo carriers, which transport petroleum and other various products stored in containers. Georges Bank is also transited by fishing vessels, cruise ships, and government vessels (e.g. Navy, Coast Guard, and research vessels). There is little seasonal variation in the main commercial shipping patterns on Georges Bank, although traffic associated with fishing vessels, tourism, and research are predominant during the summer and fall months.

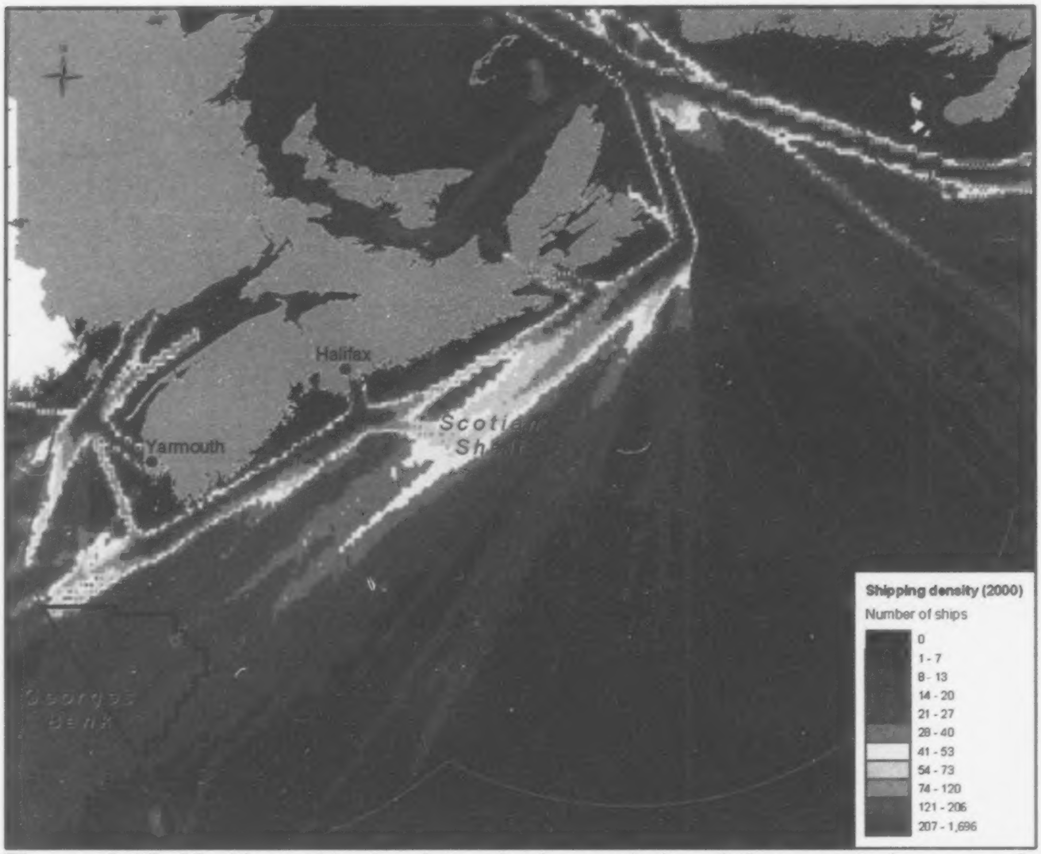

Halifax
Yarmouth
Scotian Shelf
Georges Bank
Shipping density (2000)
Number of ships
0
1 - 7
8 - 13
14 - 20
21 - 27
28 - 40
41 - 53
54 - 73
74 - 120
121 - 206
207 - 1,696

Figure 4-15. Maritime shipping intensity in proximity of the moratorium area in 2000 (inbound traffic only).

4.3.3 Scientific Research

The Atlantic Zone Monitoring Program regularly takes samples along transects, known as 'sections' (Figure 4-16). There are several sections on the Scotian Shelf: the Cabot Strait line across the Cabot Strait, the Louisbourg line across Banquereau and Misaine Banks, the Halifax line across Emerald Basin and Emerald Bank, and the Browns Bank line across Browns Bank. The program also takes samples at fixed stations near the coast, including one near the mouth of Halifax Harbour, Nova Scotia, and another near St. Andrews, New Brunswick. The program collects physical, biological, and chemical data on the marine environment.

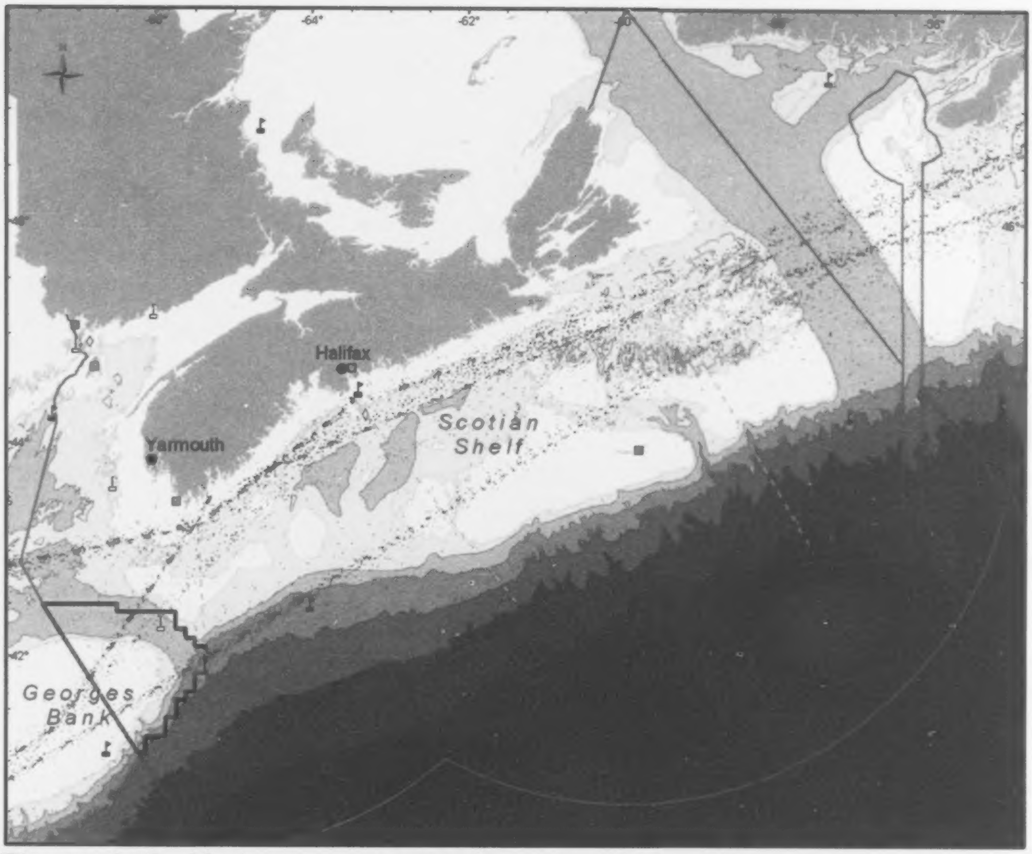


Figure 4-16. Marine research sections, sample locations, and buoys in the vicinity of the moratorium area. The dashed yellow lines represent Atlantic Zone Monitoring Program transects and the purple points are opportunistic plankton sample locations. The red flags are buoys operated by Environment Canada and the white flags are buoys operated as part of the Gulf of Maine Ocean Observing System. Drifter buoys are not shown.

Environment Canada maintains a series of moored buoys and drifting buoys to monitor marine weather and other meteorological parameters. Drifting and moored buoys are also deployed for oceanographic research projects. One long-term project is the Gulf of Maine Ocean Observing System (GOMOOS), which uses buoys and other devices to collect both oceanographic and weather monitoring data. Two of the GOMOOS buoys are in Canadian waters. There may be many other research buoys present on the Scotian Shelf and in the Bay of Fundy that are not depicted on Figure 4-16. The Continuous Plankton Recorder Survey, run by the Sir Alister Hardy Foundation for Ocean Science, has been using vessels of opportunity to collect plankton samples since 1931 (Sir Alister Hardy Foundation for Ocean Science, 2005). Samples from the Northwest Atlantic date back to 1959. The points shown on Figure 4-16 represent samples taken over the entire history of the program, although for many periods (e.g., from the late 1970s to early 1990s) coverage of the Scotian Shelf was limited (Myers et al. 1994).

Scientists at DFO monitor fish populations of the Scotian Shelf, Bay of Fundy, and Gulf of Maine on an ongoing basis. Some of the most important sources of information on the state of marine fish populations are bottom trawl surveys. These surveys target groundfish in particular, but also provide data for use in the evaluation of pelagic fish and invertebrate resources. The moratorium area is subject to annual scientific research surveys undertaken by both Canadian and American government scientists. Typically, DFO undertakes fishery trawl surveys in the Georges Bank area during the summer months. The Canadian portion of Georges Bank is also regularly accessed by United States research vessels undertaking groundfish, scallop, and small pelagic fishery surveys.

The Biodiversity Corridor located east of Georges Bank (extending from the coastal area of southwest New Brunswick south to the outer continental shelf) is also an area of significant interest to Canadian scientists studying the oceanography, productivity, and marine biology of the region. The Biodiversity Corridor encompasses several important coral areas in the region, including the Northeast Channel Coral Conservation Area located east of Georges Bank.

4.3.4 Military

Canada's maritime forces engage in a range of operations and activities including sovereignty patrols, maritime surveillance, naval training and combat readiness, search and rescue, humanitarian relief and aid to civil authorities, and operational support to other government departments, including fisheries and environmental protection (Figure 4-17). Canada's east coast naval presence is provided through MARLANT, which has its headquarters located in Halifax, Nova Scotia. To carry out its missions, MARLANT uses a range of platforms, including patrol frigates, coastal defence vessels, destroyers, submarines, ship-borne helicopters, and long-range patrol aircraft.

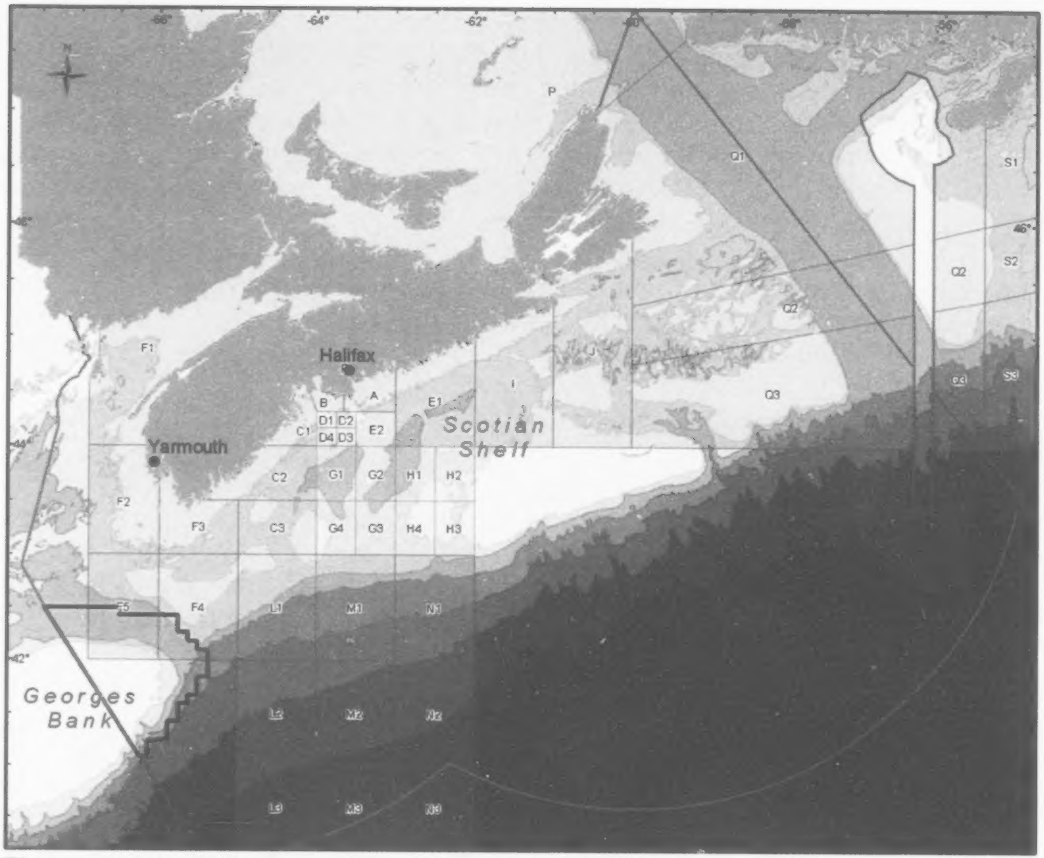

-66°
-64°
-62°
-60°
-58°
-56°
P
Q1
S1
46°
Q2
S2
Q2
J
Q3
S3
Halifax
F1
B
A
E1
I
C1
D1
D2
D4
D3
E2
Scotian Shelf
Yarmouth
44°
C2
G1
G2
H1
H2
F2
F3
C3
G4
G3
H4
H3
F5
F4
L1
M1
N1
42°
Georges Bank
L2
M2
N2
L3
M3
N3

Figure 4-17. Military exercise areas in proximity of moratorium area. Green areas represent military subsurface operation areas and yellow areas represent military subsurface operation areas and firing exercise areas.

In addition to and during the various types of missions and patrols carried out by MARLANT, naval training activities may take place in designated exercise areas in the offshore of Nova Scotia. Exercise areas are zoned for specific types of activities, such as surface and subsurface exercises, bombing practice from aircraft, anti-aircraft firing from surface vessels, and anti-surface firing from surface vessels. The most common activity in the region is subsurface training involving aircraft, surface vessels, and submarines. Live fire training is not usually conducted in the MARLANT area. Exercise areas can also be used by foreign vessels or aircraft during periodic multinational exercises or with permission from the Government of Canada. Maps, coordinates, and descriptions of military activities permitted in these exercise areas are listed in the Canadian Coast Guard Annual *Notices to Mariners.* Exercise areas F4 and F5 cover parts of the northern edge of Georges Bank and much of Northeast Channel (Figure 4-17).

A Legacy site is any property formerly owned or leased by National Defence Canada (DND), or, a definable area never owned or leased by DND for which

DND has or had an Unexploded Explosive Ordnance (UXO) responsibility. In the moratorium area, two Maritime Forces Atlantic (MARLANT) shipwrecks located in Canadian jurisdiction east of the Canada–United States maritime boundary are linked to UXO (pers comm. DND UXO and Legacy Sites Program, April 2, 2010). One shipwreck is known to contain UXO and it is possible that the second shipwreck contains UXO. In addition, on the Scotian Shelf break, a MARLANT shipwreck suspected to contain UXO is located 10 nautical miles south of the moratorium area. The list of locations of UXO Legacy Sites continues to evolve and information regarding new locations should be communicated to DND. Information on the UXO and Legacy Site program can be found at www.uxocanada.forces.gc.ca or by calling 1-800-207-0599.

4.3.5 Submarine Telecommunications

There are no active submarine telecommunication cables or power cables located in the moratorium area due to its high intensity of fishing (Figure 4-18). One abandoned cable, however, passes south of Georges Bank and one passes through the Northeast Channel. There are two active fibre-optic telecommunications cables in areas of greater water depth north (Hibernia Atlantic fibre-optic cable) and south (CANUS 1 fibre-optic cable) of the moratorium area.

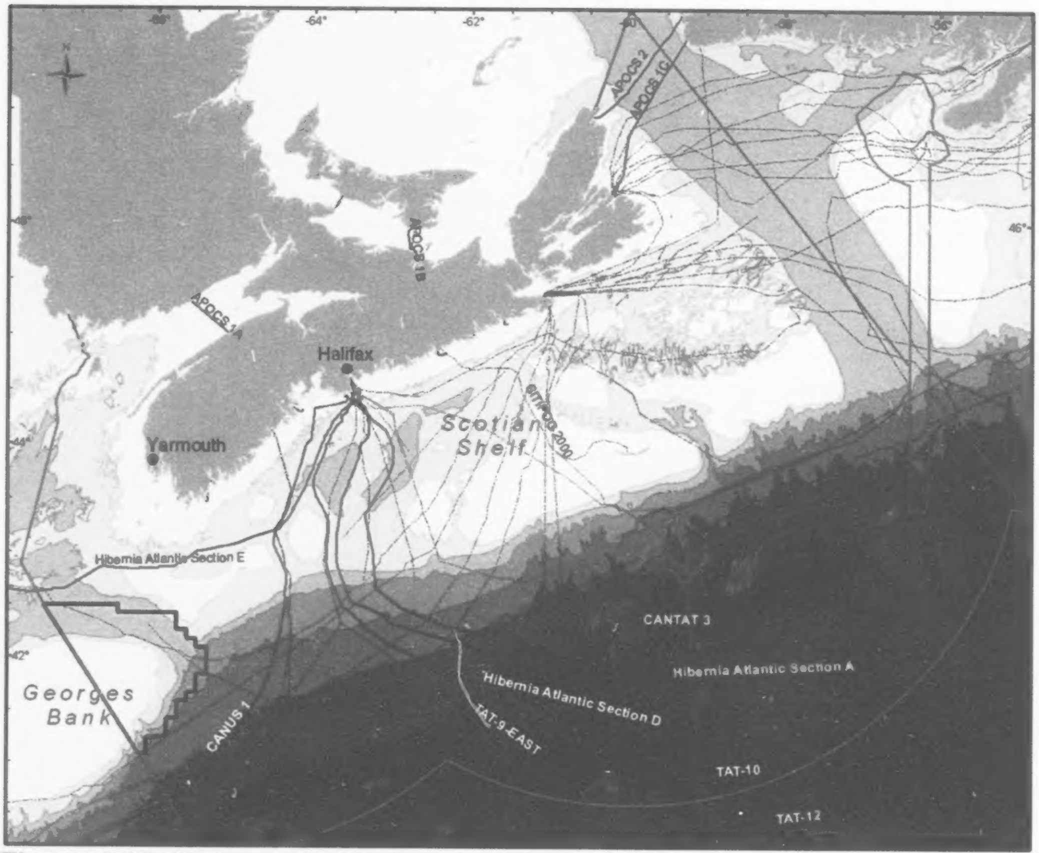

-66°
-64°
-62°
-60°
-58°
-56°
46°
44°
42°
APOCS 2
APOCS 1C
APOCS 1B
APOCS 1A
Halifax
Yarmouth
Scotian Shelf
GITPOC 2000
Hibernia Atlantic Section E
Georges Bank
CANUS 1
CANTAT 3
Hibernia Atlantic Section A
Hibernia Atlantic Section D
TAT-9 EAST
TAT-10
TAT-12

Figure 4-18. Active and abandoned submarine telecommunication cables in and around the moratorium area.

4.4 POTENTIAL INTERACTIONS OF OFFSHORE PETROLEUM ACTIVITIES WITH THE FISHING INDUSTRY OF GEORGES BANK

An offshore petroleum development project typically consists of three phases: exploration, production, and decommissioning. The exploration phase consists of the acquisition of seismic data and, in the event that a potential significant petroleum resource is indicated, an exploratory drilling program may follow. Upon identification of a commercial grade petroleum reserve, a production phase may proceed with the installation of infrastructure used to extract the petroleum resource and transport it to market. Upon completion of production, a decommissioning phase is undertaken, which typically consists of the shut-down and removal of infrastructure associated with the production phase.

This section outlines the potential interactions of the offshore petroleum industry with the fishing industry, as well as measures that are used to mitigate the interactions. The section does not discuss the potential interactions of the offshore petroleum industry with the marine environment (refer to Chapter 3.0 for potential impacts and mitigation of offshore petroleum activities on fish health and behaviour which, in turn, may have indirect effects on the fishing industry) or activities of the fishing industry that may affect the offshore petroleum industry. The aim of the section is to identify potential interactions that may arise in the presence of permitted offshore petroleum activities on Georges Bank, including: 1) access; 2) vessel and gear conflicts; and 3) accidental spills.

The section does not quantify potential interactions, rather it provides information on the types of interactions that have been observed in other offshore petroleum producing regions. The degree to which certain interactions may have an effect on the fishing industry of Georges Bank would depend on the intensity and nature of the offshore petroleum activities being permitted, which is within regulatory control. The reader is encouraged to consider the potential interactions presented below in context of cumulative interactions that may exist among multiple users of a common marine space, as well as recognize that other ocean users such as the fisheries may also exhibit interactions that may influence the offshore petroleum industry.

4.4.1 Access

A challenge in the offshore environment is the management of conflicts that may arise among multiple ocean users that share access to a common marine space. Competing access in the offshore occurs when an activity occupying a marine space influences how another ocean user may use that space. Competing access for marine space due to offshore petroleum exploration and development activities can be separated into short-term (i.e. days to months) and long-term access issues (i.e. years to decades). The duration and scale of influence on access of the fishing industry depends on the nature of an offshore petroleum activity and the number of activities occurring at a given time.

During the exploration phase, both seismic and drilling programs can result in hindered access to marine space for days to a couple of months depending on the program. Seismic programs typically extend over large areas, although the ocean space they occupy at any one time is defined by the seismic streamer configuration (up to several squared-kilometres in size) and the speed of the seismic vessel (approximately four nautical miles per hour). Seismic programs have no safety exclusion zone around the vessel and are typically carried out during periods of low sea-state. A drilling program is located about one fixed point of interest at a given time. Drilling typically lasts from one to three months. Hindered access to marine space due to drilling is confined to a 0.5 km radius safety exclusion zone around the drilling project. This equates to an area of hindered access of 0.8 km^2 for a drilling site. Drilling is not as dependent on sea-state compared to seismic surveying and may be carried out throughout the year.

The production phase can result in hindered access to marine space that can last from years to a few decades. The safety exclusion zone around a production project is typically defined by a 0.5 km radius safety (0.8 km^2 area), although this may vary in size depending on the design of the production unit. For example, the safety exclusion zone around the Deep Panuke production project located on Sable Bank of the Scotian Shelf is approximately 30 km^2 in area, due to its interconnecting field flow-lines. Other potential causes of hindered access to marine space are associated with the installation of infrastructure that service offshore petroleum projects such as pipeline installation. To date, pipelines that have been installed to service offshore petroleum projects on the Scotian Shelf have been designed (whether buried or not) to be fished over, including the use of mobile fishing gear.

The decommissioning phase typically results in no net hindered access to marine space during the removal of infrastructure (e.g. platforms and wellhead protection structures), since such infrastructure is in the safety exclusion zone defined by the production project. The decommissioning phase often returns ocean space to other ocean users. In some cases, where government regulators have deemed that it does not pose a safety hazard or interfere with other ocean users, certain offshore petroleum infrastructure has been left in place on the Scotian Shelf. To date, however, such practice has been the exception and most offshore petroleum infrastructure has been removed upon project decommissioning.

4.4.2 Vessel and Gear Interactions

Vessel and gear interactions may result from the overlapping occurrence of fishing and offshore petroleum activities. The pelagic longline fishery can have gear that extends up to 64 km in length behind the vessel. The nature of both seismic and longline fishing activities result in large areas of influence associated with each activity, as well as a large turning radii associated with each type of vessel. Furthermore, the gear associated with longline fishing activities is susceptible to considerable drift in the presence of changing wind, waves, and tides. The large area of influence and gear-drift uncertainty associated with the longline fishing industry may influence how the fishery undertakes its activity in the presence of seismic surveys, as well as more permanent offshore petroleum structures such as drilling platforms and production projects. Despite the possibility of vessel collisions and gear entanglement, to date, no seismic/longline gear entanglements have occurred in the offshore of Nova Scotia.

Potential interactions associated with the shellfish and mobile gear groundfish fisheries include loss of gear, such as trawls and traps, which may result from contact with offshore petroleum infrastructure or by collisions between offshore petroleum service vessels and fishing gear. These interactions, however, are likely to be small due to safety exclusion zones and infrastructure design (e.g. pipeline). Moreover, the few additional vessels typically associated with offshore petroleum activities are not likely to increase risks of vessel-gear interactions relative to the large number of fishing and commercial shipping vessels that routinely use the area. To date, preventative measures such as consultation and, for certain seismic surveys, the use of Fishery Liaison Officers have contributed to the mitigation of vessel and gear conflicts between the two industries.

4.4.3 Accidental Spills

There may be short-term and long-term effects to the fishing industry (including potential effects on associated industries and communities) in the event of large accidental spills associated with offshore petroleum activities. In the short term, accidental spills may result in the exclusion of fishers from an impacted area. This may result in a reduction in the supply of fish and access to the resource. Depending on the nature of the marine ecosystem, drilling or production environment, and magnitude of the spill, a long-term reduction in the supply of fish and access to the resource may result. Although the potential effects on the fishery from large scale spills are great, globally, the incident rate of large scale spills associated with offshore petroleum activity is low. Notwithstanding this fact, large spills can occur. In the presence of a large spill, in addition to potential impacts to the marine ecosystem, negative public perception of fishery resources (e.g. tainting) from a market perspective may occur. In certain instances, the demand and value of fishery products may decline for an unpredictable period of time, as a result of an accidental spill. An overview of large scale spills, regulated discharges, and the tainting of fish associated with offshore petroleum production activities are discussed in more detail in Chapter 3.0.

4.4.4 Mitigation Measures

Regulations, standards, and best practices associated with the offshore petroleum industry are used to anticipate, prevent, and mitigate user interactions in other areas of the Scotian Shelf. Discussion and improvement to various regulations, standards, and best practices that guide the offshore petroleum industry in Nova Scotia are always on-going between the Canada-Nova Scotia Offshore Petroleum Board and the fishing industry, as part of its Fishery Advisory Committee. Measures undertaken to minimize potential interactions include: consultation and environmental assessments that precede offshore petroleum exploration and development activities, use of Fishery Liaison Officers (during seismic activities) as a consultation mechanism with the fishing industry, posting of offshore petroleum activities in the Canadian Coast Guard *Notices to Mariners*, environmental effects monitoring that accompanies production activities, and the use of best practice such as the 'Statement of Canadian Practice with respect to the Mitigation of Seismic Sound in the Marine Environment' (many of the mitigation measures are described in more detail in Chapters 3.0 and 6.0).

In accordance with the 'Canada-Nova Scotia Offshore Petroleum Board Compensation Guidelines Respecting Damages Relating to Offshore Petroleum Activity', offshore petroleum operators will compensate and indemnify licenced fishers in the event that an offshore petroleum activity causes them gear damage or loss, including consequential damages during normal fishing operations. The guidelines also provide guidance for the compensation of economic losses associated with loss of catch due to gear damage or time away from the fishery due to lost or damaged gear, provided a reasonable claim can be made. In practice, few claims for lost fishing gear have been brought to the attention of the Canada-Nova Scotia Offshore Petroleum Board over the past decades.

4.5 CONCLUSION

The moratorium area hosts multiple ocean users. The predominant users of the area are the fisheries. In the region, 16 First Nations and the Native Council of Nova Scotia are fishery licence holders, which may afford rights to fish on Georges Bank for Food, Social, and Ceremonial purposes and commercial communal fishing. The Government of Canada may be required to consult Aboriginal groups regarding any potential decision that may affect their fishing activity and, where appropriate, accommodate their interests (Government of Canada, 2011). In addition, 1783 active commercial fishing licences are currently issued that permit fishing in the region. Many fisheries may operate in the area (subject to reaching their TAC) throughout the year, with the greatest number of fisheries permitted to operate from June to November. This does not mean all fisheries are operating on Georges Bank at any one time as, for example, the migratory nature of certain fish species take fleets to other parts of the Scotian Shelf (e.g. large pelagics).

The marine ecosystem of the moratorium area supports shellfish fisheries (i.e. sea scallop, lobster, and crab); groundfish fisheries (i.e. cod, haddock, and yellowtail flounder); and pelagics fisheries (i.e. swordfish, tuna, herring, and other pelagic species such as mahi mahi and shark). Presently, scallop, lobster, and haddock populations have recovered to healthy stock levels, while pelagic fisheries stock levels remain relatively stable. Groundfish fisheries stock levels, other than haddock, remain low or depleted. Despite this, Georges Bank and the Northeast Channel remain some of the most important fishing areas in the Northwest Atlantic Ocean. Many of the fishery resources are subject to transboundary management with the U.S. and international community including the North Atlantic Fisheries Organization and Transboundary Resources Assessment Committee for groundfish and the International Commission for the Conservation of Atlantic Tunas for Swordfish and Tuna.

Other ocean users of the area include maritime transportation that consists of tankers and cargo carriers, fishing vessels, cruise ships, and government vessels (e.g. Navy, Coast Guard, and research vessels). There is little seasonal variation in the main commercial shipping patterns on Georges Bank, although traffic associated with fishing vessels, tourism, and research are predominant during the summer and fall months. In addition to maritime transportation, the moratorium area is subject to annual scientific research surveys undertaken by both Canadian and American government scientists. Typically, DFO undertakes fishery trawl surveys in the Georges Bank area during the summer months. The

Canadian portion of Georges Bank is also regularly accessed by United States research vessels undertaking groundfish, scallop, and small pelagic fishery surveys. Last, abandoned telecommunications cables lay to the north and south of the Bank and the northern boundary of moratorium area is in two Canadian naval exercise areas.

Offshore petroleum rights exist in the moratorium area. BP Canada Energy Company holds 14 exploratory permits and Chevron Canada Limited holds 40 permits in the moratorium area (Figure 4-13). In addition, several exploratory permits are also held adjacent to the moratorium area. These include 16 permits held by BP and five held by Chevron. Permits held in the Georges Bank moratorium area that were issued pursuant to the Canada Oil and Gas Land Regulations are considered 'frozen' due to the moratorium (i.e. terms extended and obligations postponed). Before offshore petroleum exploration and development activities can commence on lands covered by a permit, the permit must be replaced by a negotiated exploration licence as provided in the legislation. Due to the moratorium, the time within which an exploration licence must be negotiated has been extended by the Canada-Nova Scotia Offshore Petroleum Board (the Board).

Potential interactions of the offshore petroleum industry on the fishing industry include: 1) access; 2) vessel and gear conflicts; and 3) accidental spills. Competing access occurs when an activity occupying a marine space influences how another ocean user uses that space. Competing access to marine space due to offshore petroleum activities are separated into short-term (i.e. days to months) due to seismic and drilling programs and long-term (i.e. years to decades) due to production. The duration and scale of influence on access of the fishing industry depends on the nature of an offshore petroleum activity and the number of activities occurring at a given time. Vessel and gear interactions may also result from an overlapping occurrence of fishing and offshore petroleum activities. Last, there may be short-term and long-term effects to the fishing industry (including associated industries and communities) in the event of large accidental spills associated with offshore petroleum activities. Although the potential effects on the fishery from large scale spills are great, globally, the incident rate of large scale spills associated with offshore petroleum activity is low. In the presence of a large spill, in addition to potential impacts to the marine ecosystem, negative public perception of fishery resources from a market perspective may also result.

The reader is encouraged to consider the potential interactions in context of cumulative interactions that may exist among multiple users of a common marine space, as well as recognize that other ocean users such as fisheries also may exhibit interactions that influence the offshore petroleum industry. To mitigate potential interactions of offshore petroleum activities, the industry operating in other regions of the Nova Scotia offshore abide by regulations, standards, and best practices including: consultation and environmental assessments that precede offshore petroleum exploration and development activities, use of Fishery Liaison Officers as a consultation mechanism with the fishing industry, posting of offshore petroleum activities in the Canadian Coast Guard *Notices to Mariners*, environmental effects monitoring that accompanies production activities, and the use of best practice such as the 'Statement of Canadian Practice with respect to the Mitigation of Seismic Sound in the Marine Environment'. In addition, in accordance with the 'Canada-Nova Scotia Offshore Petroleum Board Compensation Guidelines Respecting Damages Relating to Offshore Petroleum Activity', offshore petroleum operators will compensate and indemnify licenced fishers in the event that an offshore petroleum activity causes them gear damage or loss, including consequential damages during normal fishing operations.

5.0 FISHERIES SOCIO-ECONOMIC PROFILE

This chapter outlines the landings, landed values, and estimated employment associated with the fisheries of NAFO Zone 5ZE (see Figure 4-6 – Page 323 in Chapter 4.0). This zone most closely reflects the fisheries of the moratorium area. For simplicity, NAFO Zone 5ZE may also be referred to as 'the area' or '5ZE' throughout the chapter. The information regarding fishery landings and landed values that is presented was obtained from the Maritime Fishery Information System (MARFIS) databases maintained by DFO. Information regarding employment and income associated with the fisheries was estimated by DFO economists. Last, labour force information for select counties in Nova Scotia was obtained from the 2006 Census conducted by Statistics Canada.

5.1 ANNUAL TOTAL LANDED VALUE (1998–2008)

The total annual landed value represents the value of all fish species caught in NAFO Zone 5ZE per year. For some fisheries, the annual landed value has been adjusted to account for variation in prices reported to DFO between offshore and inshore fisheries while, for other fisheries, an adjustment was not required. In addition, landed values discussed in this section have been expressed in 2008 dollars. The total annual landed value of all fisheries operating in 5ZE has seen variation over the past decade (Figure 5-1). In 2000, the total landed value reached a ten year high of more than $150 million, before declining to a decade low of less than $70 million in 2005. In 2007, the total landed value for all fisheries in the area increased to approximately $84 million. Preliminary data for 2008 indicates that the total landed value has continued to increase, reaching a value of more than $105 million for the year.

The three largest fisheries by contribution to the annual total landed value of the area are the shellfish fisheries (e.g. scallop, lobster, and crab), groundfish fisheries (e.g. cod, haddock, and yellowtail flounder), and pelagics fisheries (e.g. swordfish, various tuna species, herring, and other pelagics such as mahi mahi and various shark species). On average, the shellfish fisheries contributed approximately 77% of the annual total landed value for all fisheries operating in the area from 1998 to 2008 (Figure 5-1). In contrast, the groundfish fisheries and pelagic fisheries contributed on average approximately 21% and 2% of the annual total landed value during that period, respectively. In 2008, 247 active fishery licence holders and 217 vessels operated in 5ZE. These vessels land primarily in ports located in counties throughout southwest Nova Scotia (i.e. Lunenburg, Queens, Shelburne, Yarmouth and Digby). The total landed value of fish caught from 5ZE accounted for approximately 25% of the total value of fish landed in southwest Nova Scotia in 2008. Table 5-1 shows the total landed values from 1998 to 2008 for fisheries of NAFO Zone 5ZE.

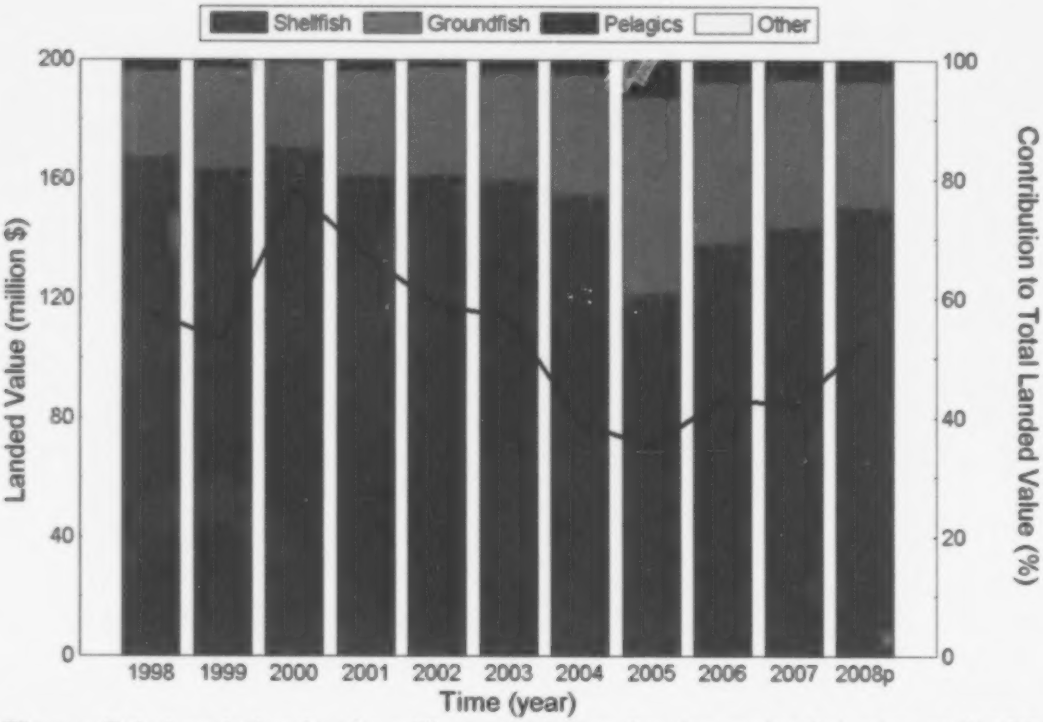


Figure 5-1. Landed value in millions of dollars for the major fisheries of NAFO Zone 5ZE (line scaled to left axis). The annual total landed value is expressed in 2008 dollars. Contribution to the total landed value of the major fisheries that occur in the area is represented by the coloured bars (bars scaled to right axis). A 'p' refers to preliminary data for 2008.

Table 5-1. Landed values in millions of dollars for the major fisheries of NAFO Zone 5ZE. The landed values are expressed in 2008 dollars. A 'p' refers to preliminary data.

Year	Shellfish (million $)	Groundfish (million $)	Pelagics (million $)	Other (million $)	Total (million $)
1998	95.90	17.07	2.04	0.02	115.04
1999	86.21	18.49	1.33	0.03	106.06
2000	132.84	22.77	0.93	0.03	156.56
2001	107.88	24.16	2.35	0.01	134.39
2002	94.50	21.66	1.32	0.02	117.51
2003	90.76	20.86	2.28	0.01	113.90
2004	60.25	16.11	1.78	0.00	78.14
2005	42.62	23.41	4.32	0.00	70.35
2006	59.54	23.83	3.12	0.00	86.49
2007	59.97	21.00	2.69	0.00	83.65
2008p	79.03	22.75	3.61	0.00	105.39

5.2 ABORIGINAL FISHERIES

In 2008, eight vessels fished six Aboriginal licences in NAFO Zone 5ZE. The vessels combined for a total landed value of approximately $1.73 million. The landings consisted primarily of groundfish, which exhibited a total landed value of approximately $1.68 million. Other species caught included swordfish, tuna, and shark. The vessels fished eight months of the year. The peak fishing month was January, when approximately 25% of the total landed value was caught. The dependency of Aboriginal licence holders on 5ZE fisheries varied from approximately 2–22% of their total catch for the year, with the average value being 8.8%. The eight vessels landed primarily in Yarmouth County, Nova Scotia.

5.3 ANNUAL LANDINGS AND LANDED VALUES BY FISHERY (1998–2008)

5.3.1 Shellfish Fisheries

The shellfish fisheries consist primarily of scallop, lobster, and various crab species such as jonah crab, rock crab, and red crab. On average, they contribute approximately 77% of the annual total landed value of all fisheries operating in the area from 1998 to 2008. In 2008, 23 vessels fished in the area for shellfish, with approximately 40% of the vessels landing at ports in Shelburne County, Nova Scotia. Collectively, in 2008, the 23 vessels landed approximately $79 million worth of shellfish.

5.3.1.1 Scallop Fishery

The scallop fishery remained the most lucrative fishery operating in NAFO Zone 5ZE from 1998 to 2008. In the late-1990s, annual landings were approximately 4000 t (Figure 5-2). This increased to more than 6000 t from 2000 to 2003. In 2004, scallop landings began to decline and reached a decade low of approximately 2700 t in 2005. Since that time, landings of scallop from the area have increased and were approximately 5900 t in 2008 (based on preliminary data for the year). This suggests a return to decade high landings observed in the early-2000s.

The landed values of scallop from the area have been adjusted to reflect the true market value of the fishery. An adjustment factor is applied due to the integrated nature of the scallop fishery, which results in reported price values for offshore scallop that often underestimate their true market value. In the case of scallop harvested in NAFO Zone 5ZE, the observed landed values were adjusted by multiplying the reported meat weight by the average price for the inshore scallop fishery for each reporting year. The value of the scallop roe landed from 5ZE was added to this estimate to get the total landed value of scallop, including roe. The landed values are expressed in 2008 dollars to permit comparison of landed values between years.

The landed value of the scallop fishery in NAFO Zone 5ZE has exhibited significant variability over the past decade. Despite relatively constant landings from 2000 to 2003, the landed value decreased from a decade high of approximately $129 million in 2000 to approximately $88 million in 2003 (Figure 5-2). In 2004, the landed value continued to decline and reached a decade low of approximately $38 million in 2005. Since that time, the landed value of scallop from the area has increased. Preliminary 2008 data estimates the landed value to be approximately $77 million.

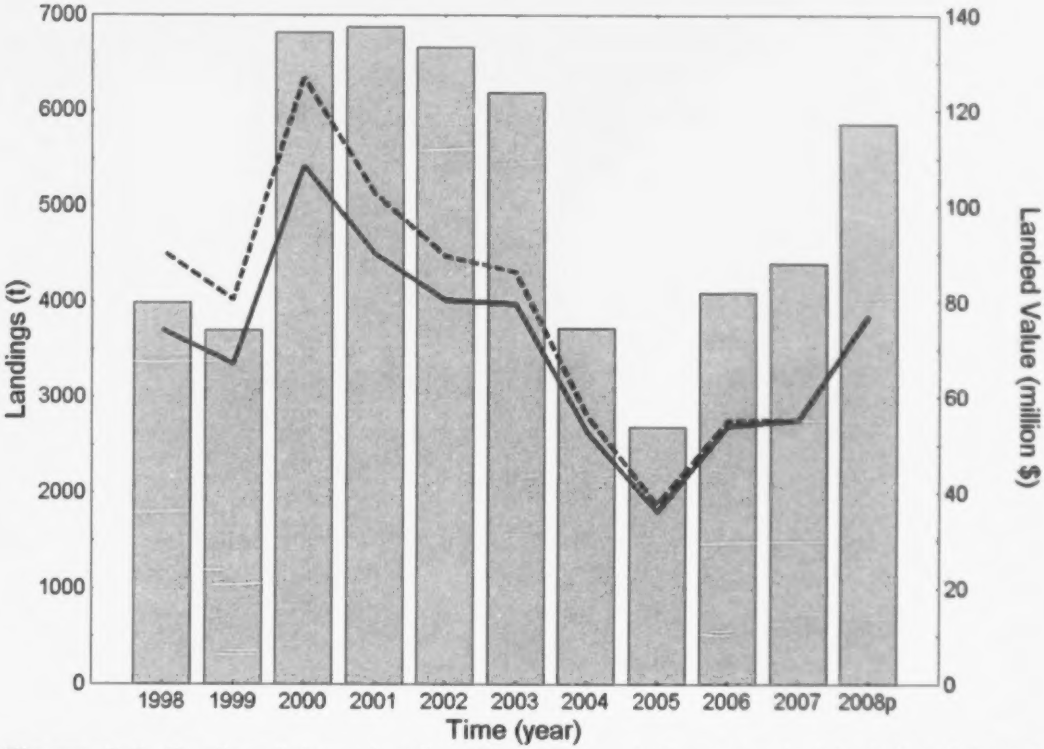


Figure 5-2. Scallop fishery landings in tonnes, t, (bars scaled to left axis) and landed values in millions of dollars (lines scaled to right axis) from 1998 to 2008. The solid line represents the annual landed value in dollars and the dashed line represents the value in 2008 dollars. A 'p' refers to preliminary data for 2008.

Vessels fishing scallop in NAFO Zone 5ZE are dependent on the area for catch. In 2008, approximately 77% of their combined total landed value came from scallop caught in NAFO Zone 5ZE. This demonstrates the importance of the area to the overall scallop fishery that operates in the offshore of Nova Scotia. Data for scallop landings and landed values from 1998 to 2008 is given in Table 5-2.

Table 5-2. Scallop fishery landings (t) and landed values in millions of dollars from 1998 to 2008. The adjusted landed values are the annual landed values expressed in 2008 dollars. A 'p' refers to preliminary data for 2008.

Year	Landings (t)	Annual Landed Value (million $)	Adjusted Landed Value (million $)
1998	3991	74.16	92.68
1999	3699	66.95	82.22
2000	6813	108.37	129.61
2001	6874	89.97	104.97
2002	6662	80.30	91.63
2003	6184	79.49	88.23
2004	3718	52.84	57.58
2005	2684	35.96	38.35
2006	4094	53.95	56.43
2007	4400	55.16	56.45
2008p	5856	76.81	76.81

5.3.1.2 Lobster Fishery

The lobster fishery contributes only a small portion to the total landed value of the shellfish fishery operating in NAFO Zone 5ZE. From 1998 to 2003, annual landings of lobster went from a high of 230 t in 1999 to a decade low of 140 t in 2003 (Figure 5-3). From 2004 to 2007, the annual landings ranged between approximately 170 t and 270 t. Based on preliminary data for 2008, lobster landings from the area have declined to approximately 203 t.

Similar to the scallop fishery, the landed values of lobster from the area have been adjusted to reflect the true market value of the fishery. In this case, the landed value of lobster was adjusted by multiplying the reported lobster weight by the average lobster price value for the inshore lobster fishery. The adjustment was done for each reporting year to capture annual changes in lobster prices. Again, the landed values are expressed in 2008 dollars to compare landed values between years. From 1998 to 2003, landed values of lobster decreased from a high of $3.8 million in 1999 to a low of $2.3 million in 2003 (Figure 5-3). From 2004 to 2007, the landed values remained between approximately $2.6 million and $4.2 million. Based on preliminary data for 2008, the lobster landed values in the area have declined to approximately $2.2 million. Data for lobster landings and landed values from 1998 to 2008 is given in Table 5-3.

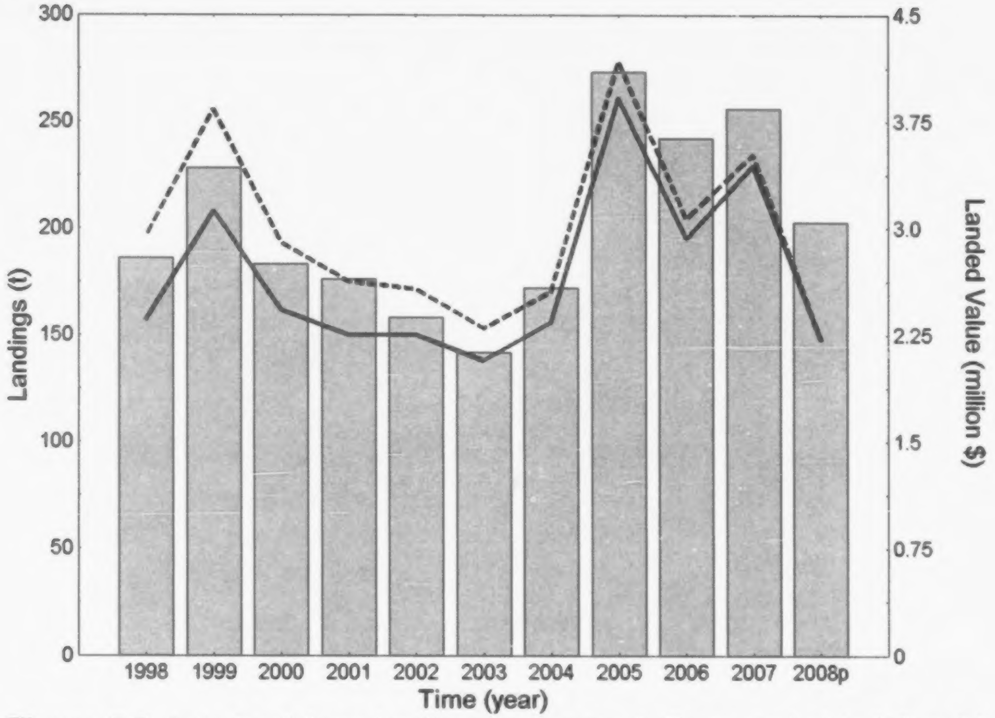


Figure 5-3. Lobster fishery landings in tonnes, t, (bars scaled to left axis) and landed values in millions of dollars (lines scaled to right axis) from 1998 to 2008. The solid line represents the annual landed value in dollars and the dashed line represents the value in 2008 dollars. A 'p' refers to preliminary data for 2008.

Table 5-3. Lobster fishery landings (t) and landed values in millions of dollars from 1998 to 2008. The adjusted landed values are expressed in 2008 dollars. A 'p' refers to preliminary data for 2008.

Year	Landings (t)	Annual Landed Value (million $)	Adjusted Landed Value (million $)
1998	186	2.35	2.94
1999	228	3.12	3.83
2000	183	2.42	2.90
2001	176	2.25	2.63
2002	158	2.25	2.57
2003	142	2.07	2.30
2004	172	2.34	2.55
2005	273	3.92	4.18
2006	242	2.93	3.06
2007	256	3.44	3.52
2008p	203	2.22	2.22

5.3.1.3 Crab Fishery

The composition of species of the crab fishery of NAFO Zone 5ZE has varied over the past decade, although it has primarily consisted of jonah crab, rock crab, and red crab. The crab fishery contributes only a small portion to the total landed value of the overall shellfish fishery operating in the area. In general, the fishery has seen considerable variation in landings over the past decade, while exhibiting a significant decline in landings over the past eight years (Figure 5-4). The annual landings of crab from the area reached a decade high in 1998 of 209 t, before declining to 101 t the following year. Landings slowly increased to 180 t in 2001, but again declined to a decade low of 0 t in 2007. Preliminary data for 2008 indicates that there were no crab landings for the year.

The landed values of crab are expressed in terms of 2008 dollars to compare landed values between years. The landed value of crab from the area observed a decade high of $0.33 million in 2000 (Figure 5-4). The value remained relatively stable until 2002. From 2003 to 2007, the landed value declined, reaching a decade low of $0.001 million in 2007. Preliminary data for 2008 indicates that the value of crab has dropped to $0 (attributable to rounding error). Data for crab fishery landings and landed values from 1998 to 2008 is given in Table 5-4.

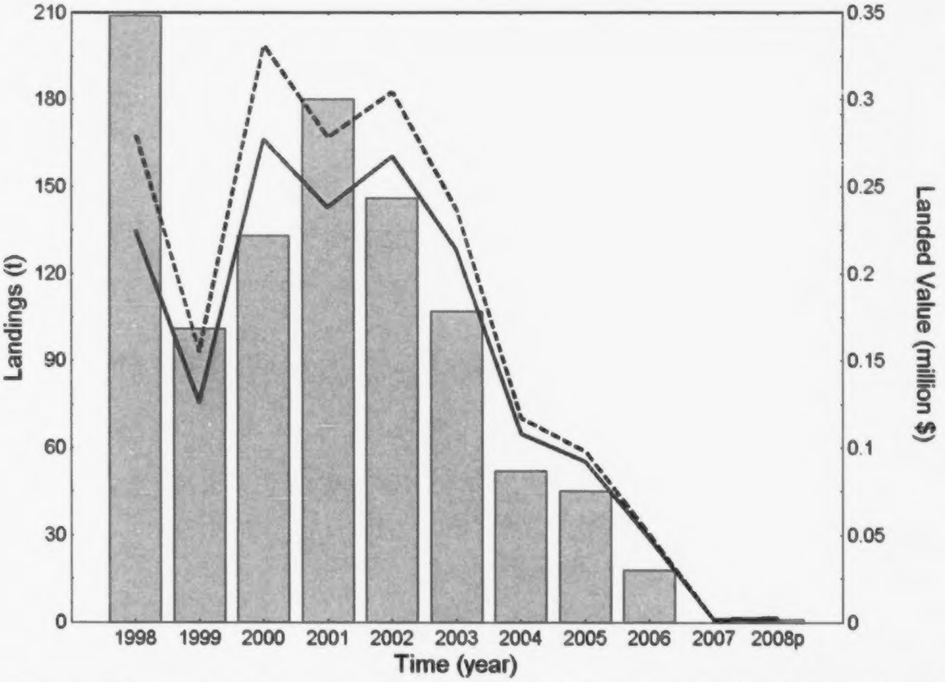


Figure 5-4. Crab fishery landings in tones, t, (bars scaled to left axis) and landed values in millions of dollars (lines scaled to right axis) from 1998 to 2008. The solid line represents the annual landed value in dollars and the dashed line represents the value in terms of 2008 dollars. A 'p' refers to preliminary data for 2008.

Table 5-4. Crab fishery landings (t) and landed values in millions of dollars from 1998 to 2008. The adjusted landed values are the annual landed values expressed in 2008 dollars. A 'p' refers to preliminary data for 2008.

Year	Landings (t)	Annual Landed Value (million $)	Adjusted Landed Value (million $)
1998	209	0.23	0.28
1999	101	0.13	0.16
2000	133	0.28	0.33
2001	180	0.24	0.28
2002	146	0.27	0.30
2003	107	0.21	0.24
2004	52	0.11	0.12
2005	45	0.09	0.10
2006	18	0.05	0.05
2007	0	0.001	0.001
2008p	0	0.00	0.00

5.3.2 Groundfish Fisheries

The groundfish fisheries consist primarily of cod, haddock, pollock and yellowtail flounder. On average, they contributed approximately 21% of the annual total landed value of all fisheries operating in NAFO Zone 5ZE from 1998 to 2008. Landings for the groundfish fisheries of the area have generally increased over the past decade (Figure 5-5). In the late 1990s, the average annual landings were approximately 9200 t. From 2000 to 2007 landings fluctuated from a low of approximately 12,000 t in 2000 to a high of approximately 18,000 t in 2005. Preliminary data for 2008 indicates an estimated landing of groundfish of approximately 17,000 t.

The landed values are expressed in 2008 dollars to compare landed values between years. From 1998 to 2001, the landed values increased from $17 million to $24 million (Figure 5-5). The landed values decreased to $16 million in 2004, before increasing to $23 million in 2005. From 2005 to 2006, the landed values remained relatively stable at approximately $23 million. In 2008, 102 vessels fished for groundfish in NAFO Zone 5ZE, with approximately 50% of the vessels landing at ports in Shelburne County, Nova Scotia. Collectively, the 102 vessels landed approximately $23 million worth of groundfish for the year. Data for groundfish fisheries landings and landed values from 1998 to 2008 is given in Table 5-5.

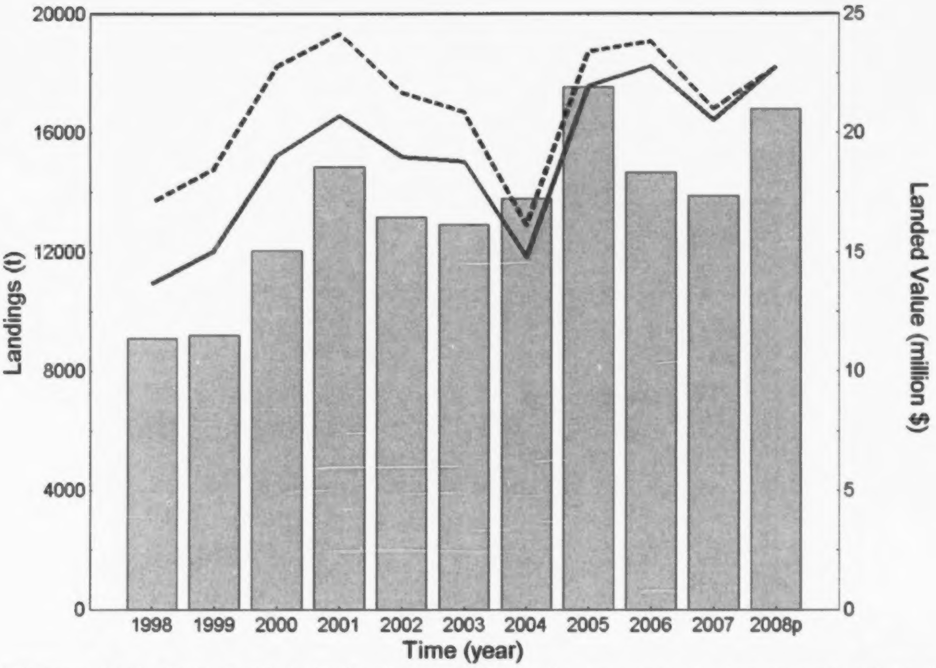


Figure 5-5. Groundfish fisheries landings in tonnes, t, (bars scaled to left axis) and landed values in millions of dollars (lines scaled to right axis) from 1998 to 2008. The solid line represents the annual landed value in dollars and the dashed line represents the value in 2008 dollars. A 'p' refers to preliminary data for 2008.

Table 5-5. Groundfish fishery landings (t) and landed values in millions of dollars from 1998 to 2008. The adjusted landed values are the annual landed values expressed in 2008 dollars. A 'p' refers to preliminary data for 2008.

Year	Landings (t)	Annual Landed Value (million $)	Adjusted Landed Value (million $)
1998	9106	13.66	17.07
1999	9205	15.05	18.49
2000	12,058	19.04	22.77
2001	14,851	20.71	24.16
2002	13,159	18.99	21.66
2003	12,918	18.79	20.86
2004	13,782	14.78	16.11
2005	17,535	21.96	23.41
2006	14,664	22.79	23.83
2007	13,884	20.52	21.00
2008p	16,803	22.75	22.75

5.3.3 Pelagic Fisheries

The pelagic fisheries consist primarily of swordfish, various tuna species, herring, and other pelagic species such as mahi mahi and various sharks species. On average, they contribute approximately 2% of the annual total landed value for all fisheries operating in the area from 1998 to 2008. In 2008, 103 vessels fished for pelagic fish species in NAFO Zone 5ZE, with approximately 75% of the vessels landing at ports in Shelburne County, Nova Scotia. Collectively, the 103 vessels landed approximately $3.6 million worth of pelagic fish for the year.

5.3.3.1 Swordfish Fishery

Over the past decade, swordfish landings have comprised the majority of the total pelagic fisheries landings caught in the area. Annual landings for the swordfish fishery in the area have generally increased over the past decade, although fluctuations have been observed between years (Figure 5-6). From 1998 to 2004, landings fluctuated from a high of 210 t in 1998 to a low of approximately 70 t in 2000. In 2005, landings increased to approximately 370 t, before declining to approximately 220 t in 2007. Preliminary data for 2008 indicates that the total swordfish landings have increased to approximately 360 t.

The landed values are expressed in terms of 2008 dollars to compare landed values between years. From 1998 to 2000, the landed values decreased from $1.7 million to $0.7 million (Figure 5-6). The landed values subsequently increased to a decade high of $3.3 million in 2005, before declining to $2 million in 2007. In 2008, 87 of the 103 vessels that fished pelagic species in NAFO Zone 5ZE reported swordfish landings with a landed value of $2 million. The 87 vessels included vessels using longline and harpoon fishing gear. Preliminary data for 2008 indicates that the landed value of swordfish has increased to $2.3 million. Data for swordfish landings and landed values from 1998 to 2008 is given in Table 5-6.

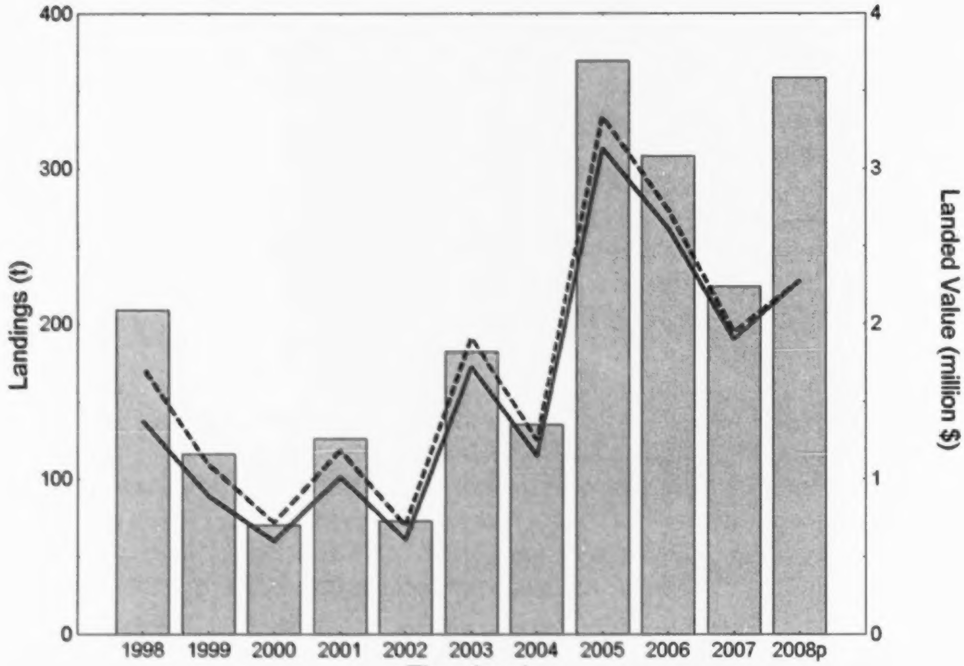


Figure 5-6. Swordfish fishery landings in tonnes, t, (bars scaled to left axis) and landed values in millions of dollars (lines scaled to right axis) from 1998 to 2008. The solid line represents the annual landed value in dollars and the dashed line represents the value in 2008 dollars. A 'p' refers to preliminary data for 2008.

Table 5-6. Swordfish fishery landings (t) and landed values in millions of dollars from 1998 to 2008. The adjusted landed values are the annual landed values expressed in 2008 dollars. A 'p' refers to preliminary data for 2008.

Year	Landings (t)	Annual Landed Value (million $)	Adjusted Landed Value (million $)
1998	209	1.37	1.72
1999	116	0.89	1.09
2000	70	0.60	0.72
2001	126	1.01	1.18
2002	73	0.61	0.69
2003	182	1.72	1.91
2004	135	1.15	1.25
2005	369	3.13	3.33
2006	308	2.61	2.73
2007	224	1.90	1.95
2008p	358	2.28	2.28

5.3.3.2 Tuna Fishery

The tuna fishery consists primarily of yellowfin tuna, bluefin tuna, bigeye tuna, and albacore tuna. Annual landings for the tuna fishery in the area have generally increased over the past decade, although there has been fluctuation between years (Figure 5-7). From 1998 to 2000, the landings were on average approximately 8 t. The landings increased to 54 t in 2001 before decreasing to a low of 7 t in 2003. From 2004 to 2007, tuna landings increased to more than 60 t per year, with the exception of 2006 when annual landings fell to 38 t. In 2008, 34 of the 103 vessels fishing pelagic species in the area reported tuna landings. Preliminary data for 2008 indicates an increase in landings of approximately 103 t.

The landed values are expressed in 2008 dollars to compare landed values between years. From 1998 to 2000, the landed values decreased from approximately $0.13 million to $0.07 million (Figure 5-7). The landed values have seen fluctuation, although a general increase in landed values has been observed over the latter part of the decade. In particular, landed values exhibited highs of $0.45, $0.96, and $0.73 million in 2001, 2005, and 2007, respectively. In contrast, lows of $0.08 and $0.38 million were observed in 2003 and 2006, respectively. Preliminary data for 2008 indicates a decade high in the landed value for tuna of approximately $1.32 million. Data for tuna landings and landed values from 1998 to 2008 is given in Table 5-7.

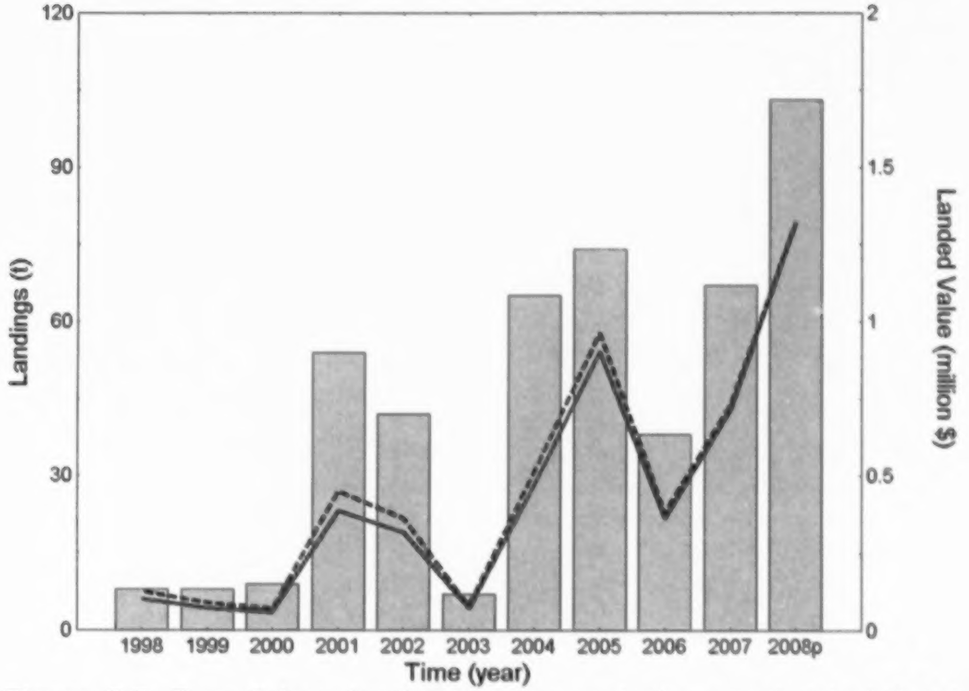


Figure 5-7. Tuna fishery landings in tonnes, t, (bars scaled to left axis) and landed values in millions of dollars (lines scaled to right axis) from 1998 to 2008. The solid line represents the annual landed value in dollars and the dashed line represents the value in 2008 dollars. A 'p' refers to preliminary data for 2008.

Table 5-7. Tuna fishery landings (t) and landed values in millions of dollars from 1998 to 2008. The adjusted landed values are the annual landed values expressed in 2008 dollars. A 'p' refers to preliminary data for 2008.

Year	Landings (t)	Annual Landed Value (million $)	Adjusted Landed Value (million $)
1998	8	0.10	0.13
1999	8	0.07	0.09
2000	9	0.06	0.07
2001	54	0.39	0.45
2002	42	0.32	0.36
2003	7	0.07	0.08
2004	65	0.47	0.51
2005	74	0.90	0.96
2006	38	0.36	0.38
2007	67	0.71	0.73
2008p	103	1.32	1.32

5.3.3.3 Herring and Other Pelagic Fisheries

The herring and other pelagic fisheries include catches of herring, mahi mahi, and various shark species. The annual landings for herring and other pelagic species was highest in 2001 at approximately 3300 t, before declining to an average landing of approximately 1700 t from 2002 to 2003 (Figure 5-8). Landings continued to decrease from 24 t in 2004 to 11 t in 2007. Preliminary data for 2008 indicates that landings have remained low at approximately 11 t.

The landed values are expressed in terms of 2008 dollars to compare landed values between years. The landed value for the herring and other pelagic fisheries was highest in 2001, with a landed value of approximately $0.7 million. The value remained close to $0.3 million in 2002 and 2003 before declining to $0.01 million in 2004 (Figure 5-8). Preliminary data for 2008 indicates a continued low of approximately $0.01 million. Data for herring and other pelagic fishery landings and landed values from 1998 to 2008 is given in Table 5-8.

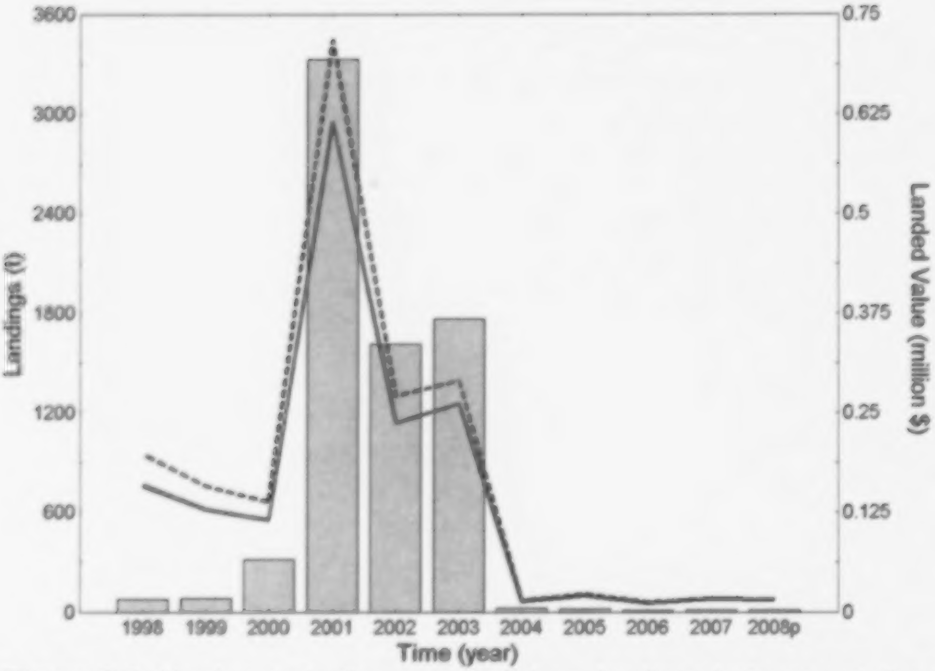


Figure 5-8. Herring and other pelagic fishery landings in tonnes, t, (bars scaled to left axis) and landed values in millions of dollars (lines scaled to right axis) from 1998 to 2008. The solid line represents the annual landed value in dollars and the dashed line represents the value in 2008 dollars. A 'p' refers to preliminary data for 2008.

Table 5-8. Herring and other pelagic fishery landings (t) and landed values in millions of dollars from 1998 to 2008. The adjusted landed value is the annual landed value expressed in 2008 dollars. A 'p' refers to preliminary data for 2008.

Year	Landings (t)	Annual Landed Value (million $)	Adjusted Landed Value (million $)
1998	78	0.16	0.20
1999	79	0.13	0.16
2000	316	0.12	0.14
2001	3326	0.62	0.72
2002	1612	0.24	0.27
2003	1766	0.26	0.29
2004	24	0.01	0.01
2005	15	0.02	0.02
2006	9	0.01	0.01
2007	11	0.02	0.02
2008p	11	0.01	0.01

5.4 MONTHLY LANDED VALUES BY FISHERY (2008)

Fishing in NAFO Zone 5ZE occurs throughout the year, although 63% of the total landed value for all fisheries is reported from April to September. Despite this, on a monthly basis, significant variation in the landed value per fishery is typically observed (Figure 5-9). Figure 5-9 outlines the 2008 reported monthly landed values of the major fisheries that occurred in NAFO Zone 5ZE: scallop, lobster, groundfish, and swordfish.

In 2008, scallop was fished year round, with over half of the annual total landed value being caught from April to August. In contrast, the bulk of the annual total landed value of the lobster fishery primarily occurred from January to June, the groundfish fishery primarily occurred from June to November and the swordfish fishery primarily occurred from June to September. In 2008, the highest combined monthly landed value of these major fisheries occurred in August, which totaled approximately $15.2 million. Variation in monthly landed values is reflective of the fishing seasons and fishing effort of each fishery.

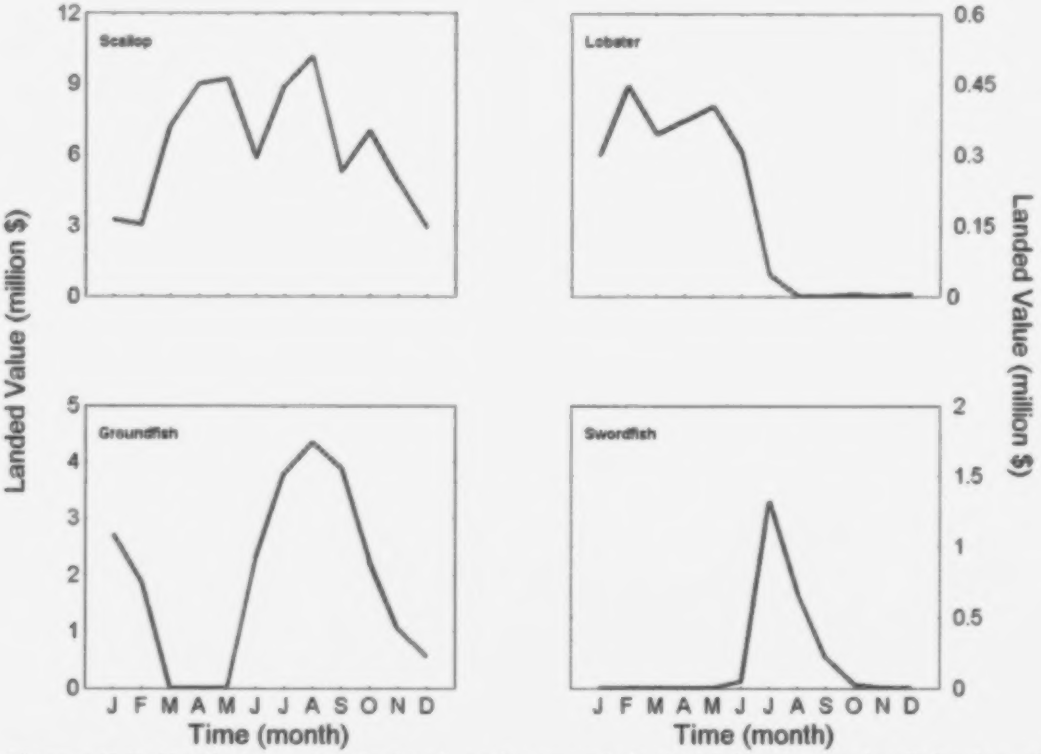


Figure 5-9. Preliminary landed values by month in 2008 for the major fisheries of NAFO Zone 5ZE: scallop, lobster, groundfish, and swordfish.

5.5 LANDED VALUES BY NOVA SCOTIA COUNTY (2008)

In 2008, more than 99% of the total landed value caught in NAFO Zone 5ZE was landed in ports in Lunenburg, Queens, Shelburne, Yarmouth, and Digby Counties of Nova Scotia. Large variation in the abundance of landings is observed between counties. Again, landings have been adjusted for variation in the fishery (if applicable) and are expressed in 2008 dollars.

In Lunenburg County, the total value of fish from all vessels landing at ports in the county in 2008 was approximately $37 million, while the total landed value of fish landed from vessels fishing NAFO Zone 5ZE was $23 million dollars (Table 5-9). This equates to 63% of the total value of fish landing at ports in Lunenburg County coming from NAFO Zone 5ZE. The shellfish fishery contributed most to the total value of NAFO Zone 5ZE landings in the county with a total value of approximately $22.8 million. In total, approximately 3% of the vessels active in NAFO Zone 5ZE in 2008 landed at ports in Lunenburg County (Table 5-10).

Table 5-9. Landed value for all fish species caught in NAFO Zone 5ZE as a proportion of the total landed value observed per Nova Scotia County in 2008. The landed values are expressed in 2008 dollars.

Nova Scotia County	Landed Value for all Fisheries (million $)	Landed Value for NAFO Zone 5ZE Fisheries (million $)	Proportion of Total Landed Value from NAFO Zone 5ZE Fisheries (%)
Lunenburg	36.87	23.17	63
Queens	14.82	5.26	35
Shelburne	161.36	49.09	30
Yarmouth	154.47	23.54	15
Digby	57.01	4.26	7
Other	-	0.07	-

Table 5-10. Landed value in millions of dollars (adjusted to 2008) for the major fisheries of NAFO Zone 5ZE per landed ports by Nova Scotia County in 2008. The number of vessels that landed at ports per county in 2008 is given in brackets. Note that the vessel count does not sum to the total, as some vessels fished more than one species or in more than one area during the year.

Nova Scotia County	Shellfish Fishery (millions $)	Groundfish Fishery (millions $)	Pelagic Fishery (millions $)	NAFO Zone 5ZE Fisheries (millions $)
Lunenburg	22.76 (4)	0.41 (2)	-	23.17 (7)
Queens	5.21 (2)	-	0.05 (3)	5.26 (5)
Shelburne	40.16 (6)	6.00 (49)	2.93 (77)	49.09 (128)
Yarmouth	8.60 (5)	14.39 (47)	0.56 (21)	23.54 (70)
Digby	2.31 (4)	1.95 (11)	-	4.26 (16)
Other	-	-	0.07 (6)	0.07 (2)
Total	79.03 (21)	22.75 (109)	3.61 (103)	105.39 (217)

In Queens County, the total value of fish from all vessels landing at ports in the county in 2008 was approximately $15 million, while the total landed value of fish caught from vessels fishing NAFO Zone 5ZE was $5 million (Table 5-9). This equates to 35% of the total value of fish landing at ports in Queens County coming from NAFO Zone 5ZE. The shellfish fishery contributed most to the total value of NAFO Zone 5ZE landings in the county with a total value of approximately $5 million. In total, approximately 2% of the vessels active in NAFO Zone 5ZE in 2008 landed at ports in Queens County (Table 5-10).

In Shelburne County, the total value of fish from all vessels landing at ports in the county in 2008 was approximately $161 million, while the total landed value of fish caught from vessels fishing NAFO Zone 5ZE was $49 million (Table 5-9). This equates to 30% of the total value of fish landing at ports in Shelburne County coming from NAFO Zone 5ZE. The shellfish fishery contributed the vast majority of the total value of NAFO Zone 5ZE landings in the county with a total value of approximately $40 million. In total, approximately 60% of the vessels active in NAFO Zone 5ZE in 2008 landed at ports in Shelburne County (Table 5-10).

In Yarmouth County, the total value of fish from all vessels landing at ports in the county in 2008 was approximately $155 million, while the total landed value of fish caught from vessels fishing NAFO Zone 5ZE was $24 million (Table 5-9). This equates to 15% of the total value of fish landing at ports in Yarmouth County coming from NAFO Zone 5ZE. The groundfish fishery contributed the majority of the total value of NAFO Zone 5ZE landings in the county with a total value of approximately $14 million. In total, approximately 30% of the vessels active in NAFO Zone 5ZE in 2008 landed at ports in Yarmouth County (Table 5-10).

Vessels landing at ports in Digby County in 2008 combined for a total landed value of approximately $57 million, while the landed value of fish from NAFO Zone 5ZE fisheries was approximately $4 million (Table 5-9). This equates to 7% of the total value of fish landing at ports in Digby County coming from NAFO Zone 5ZE. The shellfish fishery contributed the majority of the total value of vessels fishing in NAFO Zone 5ZE landings in the county with a total value of approximately $2 million. In total, approximately 7% of the vessels active in NAFO Zone 5ZE in 2008 landed at ports in Digby County (Table 5-10).

5.6 FINAL PRODUCT VALUES (1998–2008)

The landed value per fishery provides an estimate of only the landed value of the fishery. The estimate does not account for additional value added due to seafood processing. To estimate the value of seafood processing, the landed value is multiplied by a conversion factor that ranges from 1.0 to 5.1, depending on the degree of seafood processing that is required per fishery. The conversion factors are estimated based on various information sources such as exports value and qualitative information from those involved with the fishery.

Over the past decade, the final product value from all fisheries that operate in NAFO Zone 5ZE has seen considerable fluctuation (Figure 5-10). In 2000, the final product value was at a ten year high of more than $245 million, before falling to a decadal low of less than $115 million in 2005. In 2007, the final product value of fisheries in the area increased to approximately $134 million. Preliminary data for 2008 indicates that the trend in final product value of NAFO Zone 5ZE continued to increase, exhibiting an estimated value of approximately $168 million for the year. On average, seafood processing contributes an additional $63 million to the value of the fisheries (Figure 5-10). The greatest added value was approximately $90 million dollars in 2000 and the lowest added value was $44 million in 2005. On average, seafood processing added an additional 60% to the value of NAFO Zone 5ZE fisheries from 1998 to 2008.

The three largest fisheries by contribution to the final product value of the area are the shellfish fishery, groundfish fishery, and pelagics fishery. On average, the shellfish fishery contributed approximately 72% of the annual final product value of all fisheries operating in the area from 1998 to 2008 (Figure 5-10). In contrast, the groundfish fishery and pelagics fishery on average contributed approximately 26% and 2% of the annual final product value from 1998 to 2008, respectively. Table 5-11 outlines the final product values from 1998 to 2008 for fisheries that operate in NAFO Zone 5Z.

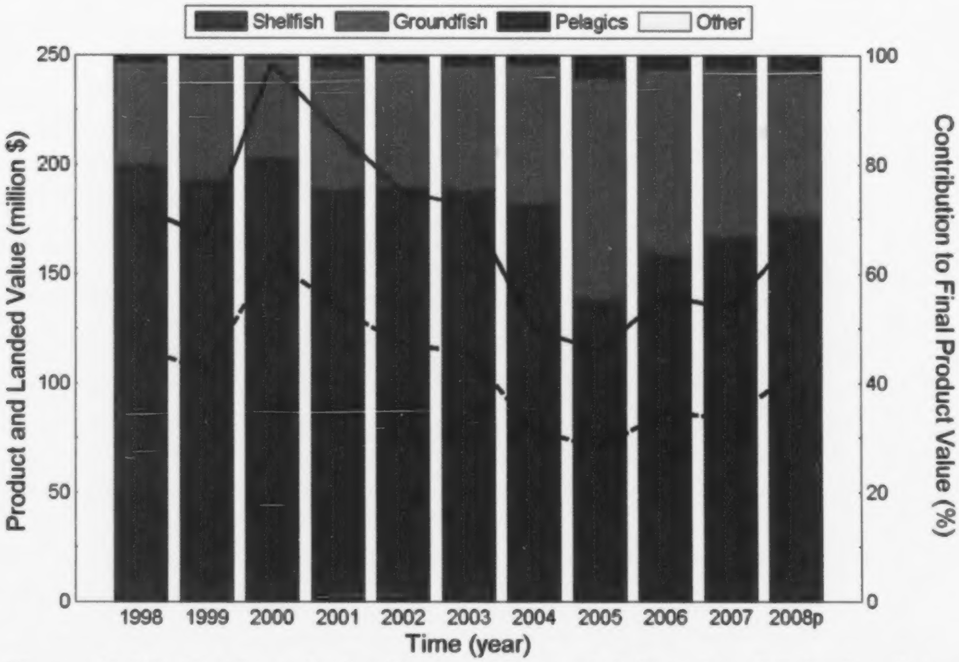


Figure 5-10. Final product value in millions of dollars for all fisheries that operate in NAFO Zone 5ZE, represented by the solid line (line scaled to left axis). The dashed line is the landed value in millions of dollars for all fisheries that operate in the area, as presented in Figure 5-1 (line scaled to left axis). The final product value is expressed in 2008 dollars. Contribution to the final product value of the major fisheries that occur in NAFO Zone 5ZE is represented by the coloured bars (bars scaled to right axis). A 'p' refers to preliminary data for 2008.

Table 5-11. Final product values in millions of dollars for the major fisheries that operate in NAFO Zone 5ZE. The final product values are expressed in 2008 dollars. A 'p' refers to preliminary data.

Year	Shellfish (million $)	Groundfish (million $)	Pelagic (million $)	Other (million $)	Total (million $)
1998	143.45	34.15	2.28	0.02	179.90
1999	128.65	36.97	1.49	0.03	167.15
2000	198.90	45.54	1.21	0.03	245.67
2001	161.47	48.31	5.29	0.01	215.08
2002	141.44	43.33	2.46	0.02	187.24
2003	135.84	41.71	3.53	0.01	181.09
2004	89.94	32.22	1.97	0.00	124.13
2005	63.16	46.82	4.75	0.00	114.74
2006	88.73	47.66	3.43	0.00	139.82
2007	89.25	41.99	2.96	0.00	134.20
2008p	118.10	45.50	3.98	0.00	167.57

5.7 EMPLOYMENT ASSOCIATED WITH FISHERIES

Many jobs are associated with the fisheries of NAFO Zone 5ZE. The following calculations are based on certain assumptions and are provided to give a general estimate of the employment numbers and salary dollars associated with processing of fish caught in the area. In general, the following information provides a context of the potential contribution of NAFO Zone 5ZE fisheries to the various communities of southwest Nova Scotia.

5.7.1 Employment from Fishing (2008)

In 2008, 217 vessels reported landings from NAFO Zone 5ZE, with 35 of the vessels reporting landings for more than one fishery. In this report, in order to estimate the total number employed in the fisheries of 5ZE, each vessel has been grouped according to its specialization. A vessel is considered a specialist if it earns 75% or more of its total landed value from a single fishery; 215 vessels were considered specialists in 2008.

To estimate employment, the number of specialist vessels per fishery was multiplied by an estimate of the average vessel crew size per vessel in each fishery. It is assumed that each crew member only fishes one species during the year. This assumption is likely valid, since many of the fisheries occur at the same time of year. In 2008, vessels fishing NAFO Zone 5ZE were estimated to employ 1059 individuals at some point during the year (Table 5-12). The shellfish fisheries employed an estimated 483 crew members aboard 23 vessels, the groundfish fishery employed an estimated 300 individuals on board 100 vessels, and the pelagic fishery employed an estimated 276 individuals on board 92 vessels (Table 5-12).

Table 5-12. Estimated number of individuals employed in select NAFO Zone 5ZE fisheries in 2008

Fishery	Number of Specialist Vessels	Average Crew Size	Estimated Employed Individuals
Shellfish	23	21	483
Groundfish	100	3	300
Pelagic	92	3	276
Total	215	-	1059

Typically, employment income per fishery is paid as a share of the total landed value of the vessel. The crew share earned varies by fishery, with estimates ranging from 35% to 45% of the vessel's total landed value. Based on the landed value per fishery in 2008 the estimated total income generated by vessels fishing in the area was approximately $43 million (Table 5-13).

Table 5-13. Estimated total income in million of dollars generated by vessels fishing in NAFO Zone 5ZE in 2008.

Fishery	Estimated Employed Individuals	Estimated Vessel Crew Income (million $)
Shellfish	483	31.6
Groundfish	300	10.2
Pelagic	276	1.3
Total	1059	43.1

5.7.2 Employment from Seafood Processing (2008)

The total number of employed positions associated with seafood processing of fish caught in 5ZE has been estimated using full time employment equivalents. In this report, the estimate of full-time equivalent employment positions followed the method outlined in the 1998 report entitled 'Georges Bank Resources: An Economic Profile' by Gardner Pinfold Consulting Economists Limited (Gardner Pinfold Consulting Economists Limited, 1988). A full-time equivalent employment designation represents full-time employment during a given month and does not necessarily represent full-year employment.

Employment associated with seafood processing is expected to vary substantially by month, due to the seasonal nature of the fishing industry. To gain an understanding of the maximum number of individuals employed by fish processors during the year, full-time employment requirements for each fishery's peak month are estimated. The number of positions is estimated by dividing the peak month's landings per fishery by a processing rate coefficient, as per the 1998 Gardner Pinfold report (Gardner Pinfold Consulting Economists Limited, 1988). This yields the number of hours required to process the peak month's catch per fishery. The total number of hours required to process the peak month's catch is then divided by the number of hours an average employee works per month. This was assumed to be 150 hours, based on a standard work week of 37.5 hours. The result is the number of full-time equivalent employees required to process each fishery's peak month landings.

In 2008, an estimated 956 full-time equivalent employment positions were required to process the peak month landings of scallop, lobster, groundfish, and swordfish caught in 5ZE (Table 5-14). This estimate is to be viewed as the maximum number of individuals required to process peak month landings, as it is possible that more than one fish species is processed at the same time or that one individual is involved with processing more than one species throughout the year.

Table 5-14. Estimated number of peak month full-time equivalent employment positions associated with seafood processing of select fishery landings caught in NAFO Zone 5ZE in 2008 The number of hours an average employee works per peak month was assumed to be 150.

Fishery	Peak Month Landings (t)	Processing Rate (t h^{-1})	Peak Month Processing Hours (h)	Peak Month Full-time Employment Equivalents
Scallop	765	0.04	19,125	128
Lobster	41	0.05	820	5
Groundfish	2970	0.025	118,800	792
Swordfish	208	0.045	4622	31
Total	3984	-	143,367	956

The majority of positions were associated with processing of groundfish, which yielded 792 full-time equivalent employment positions during its peak month (Table 5-14). This was due to the high peak month landing of groundfish in 2008 of approximately 2970 t and low observed seafood processing rate of 0.025 tonnes per hour (t h^{-1}). The scallop fishery yielded the second highest number of peak month full-time equivalent employment positions of 128. In total, it is estimated that 2015 full time equivalents were employed during peak months in 2008 either by fishing or through seafood processing of fish caught in NAFO Zone 5ZE (sum of employment in Tables 5-13 and 5-14).

A similar calculation can be used to estimate the number of full-time, full-year equivalents associated with seafood processing using annual landings per fishery in 2008. For this calculation, the total number of hours an average employee works in the year was assumed to be 1800. In 2008, an estimated 460 full-time, full-year equivalent employment positions were required to process the annual landings of scallop, lobster, groundfish, and swordfish caught in NAFO Zone 5ZE (Table 5-15). The majority of positions were associated with seafood processing of groundfish, which yielded 373 full-time, full-year equivalent employment positions. This was due to the high annual landing of groundfish of approximately 16,803 t and low observed seafood processing rate of 0.025 t h^{-1}. The scallop fishery yielded the second highest number of full-time, full-year equivalent employment positions of 81 (Table 5-15).

Table 5-15. Estimated number of full-time, full-year equivalent employment positions associated with seafood processing of select fishery landings caught in NAFO Zone 5ZE in 2008. The number of hours an average employee works per year was assumed to be 1800.

Fishery	Annual Landings (t)	Processing Rate ($t\ h^{-1}$)	Annual Processing Hours (h)	Annual Full-time Employment Equivalents
Scallop	5856	0.04	146,400	81
Lobster	203	0.05	4060	2
Groundfish	16,803	0.025	672,120	373
Swordfish	358	0.045	7955	4
Total	23,220	-	830,535	460

Last, the total annual income earned in the seafood processing industry was estimated by multiplying the estimated total annual number of hours worked processing the landings per fishery by an hourly wage for labour of $11.00 (hourly wage based on the reported value for 2008 found on the Service Canada's Labour Market Information website). Assuming an hourly wage of $11.00, it is estimated that personal income earned from processing fish caught in NAFO Zone 5ZE was approximately $9.1 million in 2008. (Table 5-16).

Table 5-16. Estimated total annual income earned in seafood processing of select fishery landings caught in NAFO Zone 5ZE in 2008. The hourly wage for labour was assumed to be $11.00.

Fishery	Annual Processing Hours (h)	Labour Wage ($\$\ h^{-1}$)	Total Annual Income Earned (million $)
Scallop	146,400	11.00	1.61
Lobster	4060	11.00	0.05
Groundfish	672,120	11.00	7.39
Swordfish	7955	11.00	0.09
Total	830,535	-	9.14

5.7.3 Employment by Nova Scotia County

Fish harvesting and seafood processing were two of the primary sources of employment in counties that reported significant fishery landings from NAFO Zone 5ZE, based on information obtained from the Statistics Canada 2006 Census. In Lunenburg County, it was estimated that 665 individuals were employed in the fish harvesting industry in 2005 (Table 5-17). An additional 520 individuals were employed in seafood product preparation and packaging. In total, it is estimated that 5% of the total experienced labour force 15 years and older residing in Lunenburg County were employed as fish harvesters or seafood processors in 2005. Given that 63% of the county's total landed value came from NAFO Zone 5ZE fisheries, it can be assumed that a significant number of these individuals were employed due to fishing in the 5ZE area.

Table 5-17. Total number employed in fish harvesting or seafood processing for select counties of southwest Nova Scotia in 2005 (from 2006 Census of Canada).

Nova Scotia County	Total Experienced Labour Force	Employed in Fish Harvesting	Employed in Seafood Product Preparation and Packaging
Lunenburg	23,330	665	520
Queens	4820	245	205
Shelburne	7715	2085	1025
Yarmouth	12,955	1590	990
Digby	9285	850	710

In Queens County, it was estimated that 245 individuals were employed in the fish harvesting industry in 2005 (Table 5-17). An additional 205 were employed in seafood product preparation and packaging. In total, it is estimated that 9% of the total experienced labour force 15 years and older residing in Queens County was employed as fish harvesters or seafood processors in 2005. Given that 35% of the county's total landed value came from NAFO Zone 5ZE fisheries, it can be assumed that approximately one quarter of these individuals were employed due to fishing in the 5ZE area.

In Shelburne County, it was estimated that 2085 individuals were employed in the fish harvesting industry in 2005 (Table 5-17). An additional 1025 were employed in seafood product preparation and packaging. In total, it is estimated that 40% of the total experienced labour force 15 years and older residing in Shelburne County was employed as fish harvesters or seafood processors in 2005. Given that 30% of the county's total landed value came from NAFO Zone 5ZE fisheries, it can be assumed that approximately one quarter of these individuals were employed due to fishing in the 5ZE area.

In Yarmouth County, it was estimated that 1590 individuals were employed in the fish harvesting industry in 2005 (Table 5-17). An additional 990 were employed in seafood product preparation and packaging. In total, it is estimated that 20% of the total experienced labour force 15 years and older residing in Yarmouth County was employed as fish harvesters or seafood processors in 2005. As only 15% of the county's total landed value came from NAFO Zone 5ZE fisheries, it can be assumed that a smaller number of these individuals were employed due to fishing in the 5ZE area.

In Digby County, it was estimated that 850 individuals were employed in the fish harvesting industry in 2005 (Table 5-17). An additional 710 were employed in seafood product preparation and packaging. In total, it is estimated that 17% of the total experienced labour force 15 years and older residing in Digby County was employed as fish harvesters or seafood processors in 2005. As only 7% of the county's total landed value came from NAFO Zone 5ZE fisheries, it can be assumed that a smaller number of these individuals were employed due to fishing in the 5ZE area.

5.8 CONCLUSION

The annual total landed value of all fisheries operating in NAFO Zone 5ZE has seen significant variation over the past decade. Since 2005, however, the total annual landed value of all fisheries has been increasing, with preliminary data for 2008 indicating a total landed value of more than $105 million (up from approximately $84 million in 2007). The three largest fisheries by contribution to the annual total landed value of the area are the shellfish fisheries (e.g. scallop, lobster, and crab), groundfish fisheries (e.g. cod, haddock, and yellowtail flounder), and pelagics fisheries (e.g. swordfish, various tuna species, herring, and other pelagics such as mahi mahi and various shark species). On average, the shellfish fisheries contributed approximately 77% of the annual total landed value for all fisheries operating in the area from 1998 to 2008. In contrast, the groundfish fisheries and pelagic fisheries contributed on average approximately 21% and 2% of the annual total landed value during that period, respectively.

Eight vessels fished six Aboriginal licences in NAFO Zone 5ZE in 2008 (5ZE most closely reflects the fisheries of the moratorium area). The vessels combined for a total landed value of approximately $1.73 million. The landings consisted primarily of groundfish, which exhibited a total landed value of approximately $1.68 million. Other species caught included swordfish, tuna, and shark. The vessels fished eight months of the year. The dependency of Aboriginal licence holders on 5ZE fisheries varied from approximately 2–22% of their total catch for the year, with the average value being 8.8%. The eight vessels landed primarily in Yarmouth County, Nova Scotia.

In addition, there were 247 active commercial fishery licence holders and 217 vessels that operated in NAFO Zone 5ZE in 2008 (note that the vessel count does not sum to the total, as some vessels harvest more than one fish species). Twenty-three vessels fished in the area for shellfish, with approximately 40% of the vessels landing at ports in Shelburne County. Collectively, the 23 vessels landed approximately $79 million worth of shellfish. In contrast, 102 vessels fished for groundfish in 5ZE, with approximately 50% of the vessels landing at ports in Shelburne County. Collectively, the 102 vessels landed approximately $23 million worth of groundfish. Last, 103 vessels fished for pelagic fish species in 5ZE, with approximately 75% of the vessels landing at ports in Shelburne

County. Collectively, the 103 vessels landed approximately $3.6 million worth of pelagic fish.

It is estimated that fish processing contributes an additional 60% to the total value of 5ZE fishery landings. Preliminary data for 2008 indicates a final product value (i.e. combined value of fishery landings with additional fish processing value) for 5ZE landings of approximately $168 million, compared to $105 million for the fishery landed values alone. Fishing vessels operating in 5ZE in 2008 provided an estimated 1059 jobs for individuals working on the vessels at some point during the year. Just under half of the employed positions were associated with shellfish fishery vessels. The total personal income earned by the individuals is estimated to be $43.1 million. In addition to fishing, processing of 5ZE fishery landings supported an estimated 956 full-time equivalent employment positions during the peak processing months of 2008. The positions generated an estimated $9.1 million in total personal income.

6.0 OCEANS, FISHERIES, SPECIES AT RISK, AND EMERGENCY PREPAREDNESS MANAGEMENT

The occurrence of new or expanding ocean activities in an area is normally associated with increased interactions amongst ocean uses. This creates a need to integrate traditional sector-based oceans management and planning in a more holistic manner that considers the ecosystem and human activities together. As government sectors responsible for different aspects of oceans management begin to discuss inter-sectoral coordination, there is opportunity to harmonize or modify sector-specific approaches to assess, manage, and plan for human activities in Canada's oceans in a manner that improves environmental protection and fosters economic development. This chapter outlines some programs and initiatives currently being undertaken at DFO that may be relevant to the management of Georges Bank.

Fisheries and Oceans Canada and the Canadian Coast Guard deliver programs and services that support sustainable use and development of Canada's oceans, waterways, and aquatic resources. It is DFO's mission to deliver to Canadians: safe and accessible waterways; healthy and productive aquatic ecosystems; and sustainable fisheries and aquaculture. Fisheries and Oceans Canada is a national and international leader in marine safety and in the management of marine resources. Departmental activities and its presence on Canadian waters help to ensure the safe movement of people and goods. In addition, DFO integrates environment, economic, and social perspectives to ensure Canada's marine resources benefit both existing and future generations of Canadians.

Fisheries and Oceans Canada manages human activities in Canada's oceans in accordance with the *Oceans Act*, *Fisheries Act*, *Species at Risk Act*, *Canadian Environmental Assessment Act*, *Canada Shipping Act*, and *Constitution Act*. The Coast Guard provides many services in support of the *Oceans Act*, *Canada Shipping Act*, and *Constitution Act*. It contributes to marine safety, protection, environmental emergency preparedness, and helps Canada to uphold its sovereignty. It also provides operational support to marine navigation, law enforcement, marine scientific research, and commerce. In particular, the Coast Guard supports DFO's overall responsibility to the national emergency preparedness program pursuant to the *Emergency Preparedness Act*.

6.1 OCEANS MANAGEMENT

6.1.1 Integrated Management

Integrated management is an approach to management whereby multiple ocean users are coordinated to reduce ecosystem and user conflicts. Three principles of integrated management are an ecosystem approach to management, sustainable development, and the precautionary approach. An ecosystem approach to management, also referred to as ecosystem-based management, is an approach to management that places the ecosystem in the forefront for consideration when determining how human activities should be undertaken in a region. Sustainable development is economic development of resources that meets the needs of the present generation of Canadians, but does not compromise the ability of future generations to meet their resource needs. Last, a precautionary approach to management and planning errs on the side of caution in decision making, in the absence of scientific certainty. The absence of scientific certainty, however, shall not halt economic development provided the risks associated with proceeding are evaluated prior to decision making (Government of Canada, 2003).

Integrated management is a fundamental component of Canada's *Oceans Act*. Canada's Oceans Strategy (2002) outlines principles, concepts, and approaches that are characteristic of integrated management and planning, and the Policy and Operational Framework for Integrated Management of Estuarine, Coastal and Marine Environments in Canada (2002) proposes an operational framework in which to achieve integrated management (DFO, 2002e; DFO, 2002f). Integrated management initiatives respect the existing divisions of constitutional and sector-based authority. The success of integrated management rests with decision-makers to exercise their powers in accordance with integrated management goals.

At present, integrated management is being undertaken by DFO in five large ocean management areas, including one on the eastern Scotian Shelf in the offshore of Nova Scotia. The pilot management areas are used to develop capacity and experience with integrated management. The pilot approach encourages integrated management practitioners to develop their own means to achieve integrated management, in relative independence of each other, while using the principles, concepts, and approaches outlined in the Policy and Operational Framework for Integrated Management to maintain a degree of national consistency. In the Maritimes Region, DFO is moving from the current pilot-based approach to establish a region-wide strategy for Integrated Management. The primary mechanisms and approaches being used for this evolution are conservation planning, state of the environment reporting, and coordination with provincial level coastal management processes.

6.1.2 Ecosystem Approach to Management

Fisheries and Oceans Canada has proposed a path forward for achieving an ecosystem approach to management in the marine environment. The overall objectives are: 1) conserve enough components and functions to maintain the natural resiliency of an ecosystem; 2) conserve enough components and functions so that an ecosystem can play its historic role; and 3) conserve physical and chemical properties so as not to negatively affect ecosystem components and functions (Jamieson and O'Boyle, 2001). Fisheries and Oceans Canada, Maritimes Region, is developing an Ecosystem Approach to

Management (EAM) Framework to guide planning, management, and decision making for all regional DFO programs. An inter-sectoral Working Group in DFO Maritimes Region has been established to develop an EAM Framework and assess its effectiveness (DFO, 2010). Two desktop pilot exercises have been initiated to apply, test, and refine the draft EAM Framework. The aim is to test the application of an ecosystem approach to management in areas where the ecology and human activities are relatively well known.

Georges Bank has been chosen as one of the desktop exercises to apply and test the EAM Framework, specifically in relation to fisheries management. The framework provides an iterative process to implement an ecosystem approach to fisheries management. Briefly, activities in the area subject DFO authority will be identified and the spatial extent and managing body will be documented. Pressures on the ecosystem associated with the different activities will be determined and prioritized, including existing (or absence of) measures used for mitigation. A means to quantify each pressure will be determined from existing information and a method to evaluate the sum of pressures will be considered; a means to assess cumulative environmental effects. Unique, sensitive, and vulnerable ecosystem components and functions (i.e. ecological indicators) that may be impacted by the pressures will also be identified, including ecological reference points for each pressure.

Pathways of effects models are visual representations of the cause-and-effect relationships between human activities and marine ecosystem components and functions. Pathways of effects models will be developed for fishery activities on the Bank, in order to characterize the interactions between activities and the ecosystem. The effectiveness of existing mechanisms to manage pressures will be determined and alternative strategies may be proposed. New strategies to mitigate any associated pressures will be proposed and tested. Performance evaluations will be conducted to determine if management mechanisms and mitigation measures are being effective. These will be adjusted as necessary, while gaps in fishery or ecosystem monitoring that inhibits the evaluations will be addressed. A review of the ecological indicators will be undertaken to determine if they remain good representations of the ecosystem components and functions of the area that remain susceptible to fishery activities.

6.1.3 Marine Protected Areas, Coral Conservation Areas, and Whale Conservation Areas

Protected areas are one of many management tools that contribute to the improved health, integrity, and productivity of marine ecosystems. A marine protected area is a coastal or marine area given special status to conserve and protect its natural habitat and marine life. Fisheries and Oceans Canada manages a number of Marine Protected Areas designated under the *Oceans Act* across Canada, including The Gully Marine Protected Area established in the offshore of Nova Scotia in 2004. In addition to The Gully Marine Protected Area, DFO is undertaking a systematic approach to identifying other unique and/or sensitive areas in the offshore of Nova Scotia that may require future management measures, including possible future *Oceans Act* Marine Protected Areas. This is part of Canada's commitment to establish a national network of marine protected areas.

Coral Conservation Areas have been established pursuant to the *Fisheries Act* as part of DFO Maritimes Region's Coral Conservation Plan. Fisheries and Oceans Canada manages two Coral Conservation Areas in the offshore of Nova Scotia: the Lophelia Coral Conservation Area located southeast of Cape Breton Island, Nova Scotia, and the Northeast Channel Coral Conservation Area located off of southwestern Nova Scotia near Georges Bank. The Northeast Channel Coral Conservation Area was selected based on results from surveys conducted by scientists at DFO and Dalhousie University, Nova Scotia (see Figure 2-25 – Page 43 in Chapter 2.0). Observations indicated signs of fishing impacts on corals, with broken live corals, tilted corals, and scattered coral skeletons being observed. Bottom-contacting gear is restricted in most of the Coral Conservation Area, with the exception of a small zone where groundfish longline fishing may occur with observer coverage.

Fisheries and Oceans Canada has established Whale Conservation Areas (also referred to as Whale Sancturaries) that contribute to the protection of the endangered North Atlantic right whale. Two Whale Conservation Areas for North Atlantic right whales exist in the offshore of Nova Scotia: the Roseway Basin located off southwestern Nova Scotia near Browns Bank; and the Grand Manan Basin located off Digby Neck, Nova Scotia, in the outer Bay of Fundy. These areas are not enforced pursuant to legislation, but rather have been managed through voluntary measures published in the Canadian Coast Guard Annual *Notices to Mariners* and through government-industry cooperation. More recently, the Roseway Basin Whale Conservation Area has been modified and designated by the International Maritime Organization as a seasonal 'Area to be Avoided' for shipping traffic. Both the legislated and voluntary approaches used to promote marine conservation and protection in Canada reflects the diverse management tools used to help advance the integrated management of its oceans.

6.1.4 Environmental Assessment

Prior to the 1970s, the impacts of human activities on the environment were not considered in a systematic manner in federal government planning and decision-making (Weston, 1992). The result was often serious or irreversible damage to the natural environment, detrimental impacts to human health, social well being and the economy, and costly compensation and remediation assumed by government (Weston, 1992). To address these issues environmental planning was proposed: planning that takes into account the potential effects of policies, plans, programs, and projects on the natural, social, and economic environments (Weston, 1992). Environmental Assessment of projects emerged as a tool to support environmental planning but, to a large degree, became the means of environmental planning in the years that followed.

The purpose of project-specific environmental assessment is to address the increasing environmental issues and lack of environmental awareness that surrounded many project developments. In 1992, the *Canadian Environmental Assessment Act* (CEAA) was enacted. The *Act* enshrined in law under what conditions and how federal authorities are to undertake project-specific environmental assessment in Canada. It defines project-specific environmental assessment as 'an assessment of the environmental effects of a proposed project that is conducted in accordance with CEAA and its regulations.'

Projects that are inconsistent with the Habitat Protection Provisions of the *Fisheries Act* may trigger an environmental assessment. Fisheries and Oceans Canada is the federal government authority that oversees the environmental assessment of projects that are inconsistent with the *Fisheries Act*. Similarly, projects in relation to offshore petroleum exploration and development are also subject to environmental assessments and, in Nova Scotia, the CNSOPB is the federal authority that ensures environmental assessment are undertaken for such projects. In many cases, multiple federal agencies coordinate and lend expertise in support of environmental assessments.

The *Canadian Environmental Assessment Act* only applies to project-specific environmental assessments. To ensure that environmental assessment would remain applicable to federal government decisions regarding policy, plan, and program proposals the Cabinet Directive on the Environmental Assessment of Policy, Plan and Program Proposals was adopted in 1990 (and subsequently revised in 1999 and 2004). Pursuant to the Directive, a strategic environmental assessment must be undertaken when a proposed policy, plan, or program is submitted to a federal Minister or Cabinet that may result in important positive or negative environmental effects (Government of Canada, 2004). The Directive applies to DFO.

6.1.5 Monitoring

Monitoring is central to informing management actions that are designed to minimize the effects of human activities on the ecosystem (GESAMP, 1991). Monitoring is defined as the systematic collection of data or information over time to determine the extent of compliance with a pre-determined standard or position (Hellawell, 1991). Environmental regulations, however, are generally minimum requirements that often promote the development of technology to meet accepted standards rather than improve industrial practice (Evans, 1986). As such, environmental monitoring has become an essential component in determining the potential impacts of a particular industry on the environment (Curran et al., 2006).

Three types of monitoring exist: compliance monitoring; surveillance monitoring; and environmental effects monitoring (McIver, 1985). Compliance monitoring ensures that a proposed development project abides by applicable laws, regulations, and permit conditions, while surveillance monitoring is used to enforce compliance (Curran et al., 2006). In contrast, EEM is used to determine if potential impacts of a proposed project exist within predicted and acceptable limits and to trigger mitigation measures if they do not (Birdsall et al., 1985; McIver, 1985; Duinker, 1989). In general, EEM is used to verify, characterize, and compare predicted environmental impacts of a proposed project to the conditions that follow and may be associated with a project development (Duinker, 1989).

Pursuant to the *Canadian Environmental Assessment Act*, proposed projects reviewed as a comprehensive study require a mandatory follow-up monitoring program. To date, all petroleum development projects operating in the offshore of Atlantic Canada have been required to undertake follow-up compliance and environmental effects monitoring. The program design follows an adaptive approach whereby iterative cycles of monitoring are reviewed on an annual or bi-annual basis. The iterative approach allows for timely management responses to potential environmental effects associated with a project, as well as continued improvement to the monitoring program. The regulatory authority responsible for overseeing monitoring in the offshore of Nova Scotia is the CNSOPB, although DFO provides support byway of its expertise in marine sciences.

6.2 FISHERIES MANAGEMENT

6.2.1 Fish Licences

In Canada, the federal government has constitutional authority over all fisheries and, in Nova Scotia, directly manages all fisheries including commercial freshwater fisheries (this is not the case in all provinces). To effectively manage fisheries, fish licences are issued by the federal Minister of Fisheries and Oceans pursuant to the discretionary authority granted under the *Fisheries Act*. A 'fish licence' authorizes a holder to harvest certain fish species or marine plants subject to the conditions attached to the licence (DFO, 1996c). In Canada, a fish licence is considered a privilege granted to an individual to harvest a Crown resource. It is not considered a transfer of resource ownership.

Licencing and management plans provide controlled approaches by which DFO manages commercial fisheries. Fish licences restrict access to fishery resources and offer a control point in which fisheries can be managed pursuant to applicable legislation, while also recognizing the status of the fish stock and applicable management directions. The *Fisheries Act* and its supporting regulations such as the Fishery (General) Regulations, Aboriginal Communal Fishing Licences Regulations, Atlantic Fishery Regulations 1985, and the

Maritime Provinces Fishery Regulations, afford DFO the authority to outline licence conditions that support fishery management measures.

Examples of management tactics that can be implemented through fish licencing, although not limited to, include: number of issued licences, setting of a total allowable catch, types of fishing gear and fishing practices, fishing locations (including closures or moratoria), vessel restrictions (e.g. size), and vessel capability (e.g. post-catch processing at sea). To maintain authority over Canada's fishery resources, fish licences are subject to an expiration date and licence renewal occurs on an annual basis. A licence is not considered active unless it is accompanied by licence conditions. As DFO implements new approaches to fisheries management, licencing will continue to provide DFO a means in which new management measures are integrated into the fisheries. Fisheries and Oceans Canada's (1996) 'Fisheries Licensing Policy for Eastern Canada – 1996' provides an overview of fish licensing in Eastern Canada. The policy was under review at the time of writing this report.

6.2.2 Aboriginal Fisheries Programs

In 1990, the Supreme Court of Canada issued a landmark ruling in the *Sparrow* decision. This decision found that Musqueam Band members have an Aboriginal right to fish for food, social, and ceremonial purposes. The Supreme Court also found that where an Aboriginal group has a right to fish for food, social, and ceremonial purposes, it takes priority, after conservation, over other uses of the resource. In addition, the Supreme Court indicated the importance of consulting with Aboriginal groups when their fishing rights might be affected. The Government of Canada may be required to consult Aboriginal groups regarding any potential decision that can affect their fishing activity and, where appropriate, accommodate their interests (Government of Canada, 2008).

In response to the decision and, to provide stable fisheries management, DFO implemented the Aboriginal Fisheries Strategy (AFS) in 1992. The AFS is applicable where DFO manages the fishery and where land claims settlements have not already put a fisheries management regime in place. The objectives of the AFS are: 1) provide a framework for the management of fishing by Aboriginal groups for food, social, and ceremonial purposes; 2) provide Aboriginal groups with an opportunity to participate in the management of fisheries, thereby improving conservation, management, and enhancement of the resource; 3) contribute to the economic self-sufficiency of Aboriginal communities; 4) provide a foundation for the development of self-government agreements and treaties; and 5) improve the fisheries management skills and capacity of Aboriginal groups.

The AFS is of assistance to DFO in managing the fishery in a manner consistent with the *Sparrow* decision and subsequent Supreme Court of Canada decisions. The AFS seeks to provide for the effective management and regulation of fishing by Aboriginal groups through the negotiation of mutually-acceptable and time-limited fisheries agreements between DFO and Aboriginal groups. Where agreement cannot be reached with an Aboriginal group, DFO will review the consultations with the group and the Minister of Fisheries and Oceans will issue a communal fishing licence to the group, containing provisions that the Minister believes are consistent with the *Sparrow* decision and subsequent Supreme Court of Canada decisions. The licence allows the group to fish for food, social, and ceremonial purposes. Where DFO reaches agreement with an Aboriginal group, the Minister of Fisheries and Oceans will issue a licence to the group that reflects the agreement reached. Since its inception, the AFS program has resulted in better monitoring of Aboriginal fishing, improved co-operation on enforcement, more selective fishing, and the creation of jobs for Aboriginal peoples in many areas of the fishery such as commercial fishing, processing, monitoring, and fishery enhancement activities.

In 1999, the Supreme Court of Canada issued another landmark ruling in the *Marshall* decision. The decision found that 34 Mi'kmaq and Maliseet First Nations in the Maritimes Region and the Gaspé region of Quebec have a treaty right to hunt, fish, and gather in pursuit of a “moderate livelihood” arising out of the Peace and Friendship Treaties of 1760 and 1761. Since the *Marshall* decision, DFO has negotiated fishing agreements and undertaken a variety of initiatives to support the participation of the affected Mi'kmaq and Maliseet First Nations of the Maritimes region of Atlantic Canada and the Gaspé region of Quebec in commercial fisheries. Since 1999, DFO in these regions have invested in the *Marshall* Response Initiative (MRI), reaching agreements with 32 of 34 eligible First Nations groups. The initiative ended March 31, 2007, and provided support for increased commercial fisheries access (e.g. including fishing vessels, fishing gear, and commercial fisheries infrastructure) and internal governance development. It has become a significant driver for economic development in many First Nation communities of these regions.

In addition to AFS and MRI, DFO continues to work with Aboriginal groups in support of strengthened Aboriginal fisheries. For example, the Atlantic Integrated Commercial Fisheries Initiative (AICFI) supports the building of management and governance skills in Aboriginal commercial fisheries through training and mentoring. This program includes the creation and implementation of business development plans and the integration of fisheries management systems, as well as a mentoring program from 2004 to 2008, which saw hundreds of Aboriginal fishers matched with non-Aboriginal mentors to share fishing knowledge and foster the transfer of skills. In addition, the Aboriginal Aquatic Resource and Oceans Management (AAROM) program assists Aboriginal groups to acquire the capacity to successfully manage their activities around the resource and to participate more effectively in the multi-stakeholder and other decision making processes used by DFO for aquatic resources and oceans management. Last, Aboriginal Funds for Species at Risk (AFSAR) support Aboriginal groups and communities in building capacity to allow for their participation in the implementation of the *Species at Risk Act*, as well as their involvement in activities that protect or conserve critical habitats of species at risk.

Fisheries and Oceans Canada in the Maritimes Region continues to work towards longer-term fishing arrangements with Mi'kmaq and Maliseet First Nations through processes being led by Aboriginal Affairs and Northern Development Canada. Today, First Nations are participating more fully in DFO decision-making processes and sharing their views with industry and DFO regarding fishery resource management issues.

6.2.3 Sustainable Fisheries Framework

The Sustainable Fisheries Framework pulls together, in a cohesive package, both new and existing fisheries management policies and program tools such as an ecosystem approach to management, a fishery decision making framework that incorporates a precautionary approach to management, policies to manage the impacts of fishing on sensitive benthic and fisheries for forage species, and a Fishery Checklist. Together, these help DFO identify gaps in fishery program delivery and guide continual improvement in support of sustainable fisheries.

The fishery decision-making framework will provide guidance for developing decision rules on a fishery-by-fishery basis. The framework is designed to avoid significant downside risks to a fishery stock, while encouraging improved long-term economic performance in the fishery. The sensitive benthic areas policy will help guide decisions to mitigate or avoid the impacts of fishing practices in sensitive benthic areas. It will outline additional data collection requirements for fisheries to help identify sensitive benthic areas and a process to assess the impacts of fishing on identified sensitive benthic areas through risk analysis. The forage species policy provides a framework that ensures fisheries for forage species are conducted in a manner that is compatible with conservation of the entire ecosystem and that their sustainability is evaluated in that larger context.

The Fisheries Stewardship and Sustainability Checklist will provide a tool to assess the sustainability of a fishery including application of the ecosystem approach to management, a precautionary approach to management, and other appropriate considerations. Fishery Checklists help monitor a fishery's progress to meet conservation and sustainability goals and provide consistent information collection for reporting purposes. This, in turn, helps Canada identify information and knowledge gaps and prioritize science and management efforts to make improvements to managing a fishery. It will also provide key support to the Canadian fishing industry, as demands increase in international markets for evidence of fishery sustainability. Last, the Integrated Fisheries Management Plan process is also being revised to reflect the overall ecosystem and precautionary approaches to fishery management. Integrated Fisheries Management Plans identify objectives relating to conservation, management, enforcement, and science for individual fisheries. They also describe access and allocations among various fish harvesters and fleet areas. The plans incorporate biological and socio-economic considerations that are factored into fishery harvest decisions.

Georges Bank fisheries will implement the Sustainable Fisheries Framework objectives as part of the regional ecosystem approach to management and through the new Integrated Fisheries Management Plan process. For example, the offshore scallop Integrated Fisheries Management Plan was revised in 2010 to reflect the framework's objectives. The application of the ecosystem approach to fisheries management is currently being tested for the Georges Bank pilot area, in order to assess the utility of the ecosystem approach to management framework. In short, the primary goal of the Sustainable Fisheries Framework is to ensure that Canada's fisheries are environmentally sustainable and continue to support economic prosperity. This means maintaining a sustainable balance between healthy fish stocks and marine environments that allow for prosperous fisheries. The framework responds to Canadians desires for more predictability, stability, and transparency from Canada's fisheries management regimes, as well as clear accountability.

6.2.4 Marine Stewardship Council Certification

The concept of sustainability has entered into the collective consciousness of governments, non-governmental organizations, industries, and consumers in all parts of the world. Increasingly, sustainability is becoming part of mainstream consumerism through certification programs for wild fish stock management. The global sale of fish is increasingly being affected by demands from buyers for assurances of sustainability. Eco-certification is a third party, independent review and assessment of the sustainability of a given fishery.

The Food and Agriculture Organization of the United Nations (FAO) has written 'Guidelines for the Eco-labelling of Fish and Fishery Products from Marine Capture Fisheries', which supports labelling schemes that promote products from well-managed marine capture fisheries and that focus on sustainable use of fisheries resources (FAO, 2005). The current international standard for eco-certification of wild capture fisheries and the only recognized FAO compliant regime is the Marine Stewardship Council (MSC). Under the MSC program, the successful completion of the fishery assessment process allows the proponent to use a logo to demonstrate the sustainability of a seafood product to seafood buyers and consumers. Fisheries and Oceans Canada is mandated to manage fisheries in a sustainable manner on behalf of the Canadian public and it is important that the department meet and exceed internationally accepted standards for sustainable practice.

Certification under MSC is a voluntary program. It is entered into by industry representatives of fisheries where that certification confers a benefit and where the fishery is likely to be considered well managed and sustainable. Several

Canadian fisheries have either entered into or successfully completed the sustainability certification. Certification is particularly important for Georges Bank fisheries, as all current major fisheries are undergoing certification. There are no other fishing grounds in Canada in which this has occurred. The current status of certification for the major fisheries of Georges Bank is:

Scallop fishery – The offshore scallop fishery, including St. Pierre Bank in Scallop Fishing Areas (SFA) 10, 11, and 12, the Eastern Scotian Shelf in SFA 25, Browns and German Bank in SFA 26, and Georges Bank in SFA 27, entered MSC assessment in September 2008. The fishery was certified as sustainable on March 25, 2010.

Lobster fishery – The lobster fishery in Lobster Fishing Area 41, which extends from the Canada–United States maritime boundary (or Hague line) on Georges Bank to the Laurentian Channel off Cape Breton, entered MSC assessment in December 2008. The fishery was certified as sustainable on June 2, 2010.

Haddock fishery– The Scotia-Fundy haddock fishery, including the Southern Scotian Shelf, Bay of Fundy, and Gulf of Maine Northwest Atlantic Fisheries Organization Areas (NAFO) 4X, 5Y, and Georges Bank NAFO Area 5ZE, entered MSC assessment in June 2009. The fishery was certified as sustainable on October 22, 2010.

Swordfish fishery – The Northwest Atlantic Canada harpoon and longline swordfish fishery in NAFO Areas 3, 4, 5, and 6, including the Georges Bank NAFO Area 5ZE, entered MSC assessment in June 2009. The harpoon fishery was certified sustainable on June 18, 2010. The Certifying Body has recommended that the fishery be certified, and the certification report is undergoing public comment.

6.3 SPECIES AT RISK MANAGEMENT

In recognition of the social, cultural, and economic value of aquatic species in Canada, the Government of Canada enacted the *Species at Risk Act* (SARA) in 2003 to provide the legal protection for species at risk. The *Act* is intended to complement existing legislation such as the *Oceans Act* and *Fisheries Act* to fulfill Canada's commitment to conserve biological diversity and to the principle that, if there are threats of serious or irreversible damage to a wildlife species, cost-effective measures to prevent the reduction or loss of the species should not be postponed in the absence of scientific certainty.

Although Environment Canada has the lead responsibility for protecting species at risk, aquatic species fall under the jurisdiction of DFO. The first step in the SARA process is a species assessment undertaken by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC). Upon recommendation from COSEWIC of listing a species on Schedule 1 of SARA, DFO undertakes consultation with affected parties, develops a socio-economic assessment, and completes a science-based Recovery Potential Assessment to inform the Minister of Environment in a decision. Schedule 1 is the official list of wildlife species at risk in Canada. It includes species that are extirpated (extinct in Canada), endangered, threatened, and of special concern. Once a species is listed on Schedule 1, Protection and Recovery Planning measures are developed and implemented.

Recovery Planning includes a wide range of measures to restore populations of species at risk including the protection of species and their habitat from further harm through the development of protection measures and mitigation strategies. Fisheries and Oceans Canada is committed to protecting aquatic species at risk utilizing the best available scientific information, as well as in a cooperative manner that includes consultation and collaboration with stakeholders. Following the principle of cooperation, the role of the Aboriginal peoples in the conservation of wildlife in Canada is essential and will be complimented by the efforts of all Canadians in the conservation, protection, and recovery of species at risk. Community-based stewardship activities, knowledge, and interests, including socio-economic interests and traditional ecological knowledge, are used in developing and implementing recovery and protection measures.

Any aquatic species listed as extirpated, endangered, or threatened requires DFO to develop a recovery strategy and action plan that outline recovery goals and objectives, as well as the actions needed to reach the objectives that facilitate the recovery of listed species. Generally, a recovery strategy includes information on habitat, details of protection measures, and an evaluation of socio-economic costs and benefits. The action plan is the second element of the *Act's* two-part recovery planning process, which is used to implement projects and activities to improve species status.

It is important to note that every recovery strategy or action plan will include the identification and protection of critical habitat, as well as identify human activities that are likely to harm the at risk species. Critical habitat is vital to the survival or recovery of wildlife species and may be identified as a breeding site, nursery area, or feeding area. For species at risk listed as endangered or threatened, such habitats are of the utmost importance. The *Species at Risk Act* makes it illegal to kill or harm a species at risk or destroy its critical habitat. These prohibitions may impose new restrictions on existing or new development and construction activities. Aquatic species listed in Schedule 1 of SARA as Special Concern also require the development of a management plan by DFO, which differs from a recovery strategy and action plan. A management plan sets goals and objectives for maintaining sustainable population levels of one or more species that are particularly sensitive to environmental factors, but are not yet considered in danger of becoming extinct.

To achieve the goals and objectives identified in the recovery planning phase of the species at risk program, monitoring programs are developed and implemented to ensure that species at risk are protected. Monitoring programs are designed to detect changes in the status of a species, determine the effectiveness of protection and recovery measures, and to assess progress toward achieving recovery goals and objectives. Ongoing consultations are held with affected parties to ensure that new management measures and prohibitions are well publicized.

The federal Minister of Fisheries and Oceans has the authority to authorize activities that could affect an aquatic species protected under SARA, only if the activities do not jeopardize the survival or recovery of the at risk species. To do so, the Minister must believe: the activity is scientific research relating to the conservation of the species and is conducted by qualified persons; the activity benefits the species or is required to enhance its chance of survival in the wild; or affecting the species is incidental to carrying out the activity. If an individual plans to carry out activities that may impact a listed species they require a permit under SARA (referred to as a Section 73 permit). In the application for a SARA Section 73 permit, which can be obtained at the SARA public registry at www.sararegistry.gc.ca, the applicant must demonstrate awareness of the provisions of SARA and measures to be taken to minimize harm to all listed species that may be affected by the proposed activity.

The Government of Canada recognizes that it must protect species at risk, but also maintain sustainable economic development and prosperity. Every effort will be made to work with the fishing, aquaculture, and other industries to meet the objectives of SARA, while minimizing its impact on individuals, communities, and businesses. It is conceivable that businesses may have to adapt the ways in which they operate; where that is the case DFO will communicate clearly what needs to be done to avoid uncertainty. Fisheries and Oceans Canada is committed to work as closely as possible with stakeholders, to make sure that species at risk recovery planning and protection measures are practical, effective, and in keeping with a sound management approach. The success of SARA depends on cooperation between government, industry, and the broader Canadian public.

6.4 MARINE ENVIRONMENTAL EMERGENCY PREPAREDNESS AND RESPONSE MANAGEMENT

Effective preparedness and response to marine environmental emergencies (e.g. pollution incidents such as spills or discharges) is of particular importance to the Government of Canada. In Nova Scotia, the CNSOPB is the lead federal agency that oversees the regulation of petroleum exploration and development activities in the offshore, including, but not limited to, operations on related installations, vessels, and aircraft. The CNSOPB sets out the responsibilities that offshore petroleum operators must abide by in the event of a pollution incident associated with a petroleum-related activity at sea (CNSOPB, 2009). As a condition of CNSOPB approval, offshore petroleum operators must demonstrate ability to respond to environmental emergencies by way of an Environmental Protection Plan. Depending on the nature of a potential pollution incident, other government agencies such as the National Energy Board, Fisheries and Oceans Canada, and Transport Canada may also exercise their authority pursuant to other applicable legislation.

Potential causes of marine pollution incidents associated with offshore petroleum activities include: extreme weather events, fires and explosions, collisions between service vessels, other vessels, and exploration and development infrastructure (e.g. platforms), loss of well control, and accidental hydrocarbon release during processing, storage, and transport (CNSOPB, 2009). In the event of a significant spill, the CNSOPB has an Emergency Response Plan that would be activated. Depending on the significance of the spill and the offshore petroleum operator's response, the Board's role ranges from monitoring of the operator's activities, giving direction to the operator or, in the most severe case, managing the spill response.

In the event of a pollution incident associated with offshore petroleum activities, the Canadian Coast Guard (CCG) has a memorandum of understanding with the CNSOPB to provide response capability. In order to respond to an environmental emergency in a timely manner, the CCG maintains a number of equipment depots throughout coastal communities in Canada that support the containment and remediation of discharges and spills. Regionally, these are located in select communities throughout Nova Scotia, Prince Edward Island, and New Brunswick. This is complemented by certified, private response organizations that maintain equipment depots located throughout Canada, to which offshore petroleum operators may have working arrangements for support in the event of a marine enviromental emergency. Privately-owned response organizations in vicinity of the Nova Scotia offshore are located in Halifax, Nova Scotia, Point, Tupper, Nova Scotia, and Saint John, New Brunswick.

Maritime operators responsible for a discharge, management, or control of a substance immediately before an environmental emergency or, cause or contribute to an environmental emergency, have a legal obligation to report them to the appropriate authorities pursuant to the *Canadian Environmental Protection Act*. Operators may also have obligation to report pursuant to legislation that governs the activity that they are undertaking in the offshore. For example, pursuant to the *Canada-Nova Scotia Offshore Petroleum Resources Accord Implementation Act*, petroleum discharges associated with offshore petroleum exploration and development activities must be reported immediately or as soon as reasonably possible. In addition, pursuant to the *Act*, offshore petroleum operators are legally obligated to take reasonable measures to prevent a deposit or to remedy or mitigate any further damages to minimize potential impacts of the discharge on the marine environment. In the event that a pollution incident has an adverse effect on the marine environment, the violator may be susceptible to fines and/or imprisonment upon conviction pursuant any one of the *Canadian Environmental Protection Act*, *Fisheries Act*, *Canada-Nova Scotia Offshore Petroleum Resources Accord Implementation Act*, *Canada Shipping Act*, or other applicable legislation.

The CCG is the lead government agency for either a ship-source or spill of unknown origin into the marine environment. Where the polluter is adequately responding, the CCG acts as the Federal Monitoring Officer, monitoring the cleanup efforts of the polluter. In situations where polluters are unknown, unwilling, or unable to respond to a marine pollution incident the CCG acts as the On-Scene-Commander and manages the cleanup efforts. In regard to an environmental emergency associated with offshore petroleum activities, the CCG would assume the role of a resource agency providing support to the CNSOPB. The CCG Marine Spill Contingency Plan defines the scope and framework within which the CCG is prepared for and responds to a marine enviornmental emergency (CCG, 2009). Integral to successful implementation of the plan are Regional Contingency Plans and Area Contingency Plans that set out direction and operational measures appropriate for the response to an environmental incident in a specific geographic region or local area.

Of particular concern in some areas of the Maritimes Region is the potential for trans-boundary migration of a spill or discharge into adjacent waters of the United States (e.g. Georges Bank). Under such circumstances, environmental preparedness and response is set out in the Canada–United States Joint Marine Pollution Contingency Plan (JCP) and, specific to the Maritimes Region, the JCP Atlantic Geographic Annex known as CANUSLANT (CCG and USCG, 2009). In support of the CCG response to an environmental emergency set out in its contingency plans, Environment Canada oversees national and regional committees that provide advice on how to prevent, plan for, and respond to an environmental emergency (Environment Canada, 2009). The regional committees are referred to as Regional Environmental Emergency Teams (REET). They consist of representatives from various government agencies (at all levels of government) responsible for environmental protection. The intent of REET is to support a 'one window approach' to the provision of advice that is representative of expertise from multiple government agencies.

Regional Environmental Emergency Teams undertake two main roles in emergency preparedness: planning and response. In its planning function, REET members meet to exchange scientific and technical information on matters such as contingency planning and spill response, update and review their respective roles in any emergency response situation, and participate in emergency response exercises. In its response function, REET acts as a team of advisors to the On-Scene-Commander and/or Federal Monitoring Officer. In many instances, REET communicates its advice by way of the CCG. In the Maritimes Region, DFO plays a large role in REET due to its breadth of expertise regarding the marine environment.

6.5. CONCLUSION

Fisheries and Oceans Canada and the Canadian Coast Guard deliver programs and services that support safe and accessible waterways, healthy and productive aquatic ecosystems, and sustainable fisheries and aquaculture. The Department is a national leader in marine safety and in the management of oceans and aquatic resources pursuant to the *Oceans Act*, *Fisheries Act*, *Species at Risk Act*, *Canada Shipping Act*, and *Constitution Act*. Management decisions made by the Department may also be subject to the *Canadian Environmental Assessment Act* and the Cabinet Directive on the Environmental Assessment of Policy, Plan and Program Proposals for Strategic Environmental Assessment.

Fisheries and Oceans Canada delivers programs and services in support of sustainable oceans management that is guided by a precautionary approach, ecosystem approach, and integrated approach to decision making. A precautionary approach recognizes that the absence of scientific certainty shall not be a reason to stall economic development, although all risks in proceeding shall be evaluated prior to decision making (Government of Canada, 2003). An ecosystem approach places the ecosystem at the forefront of decision-making in managing a resource. An integrated approach coordinates management between stakeholders of all human activities in a management area, so that human-ecosystem and human-human conflicts can be anticipated, prevented, and minimized. The Oceans Management Program promotes integrated management through the Eastern Scotian Shelf Integrated Management Initiative. It also promotes marine conservation through Marine Protected Areas, Coral Conservation Areas, and Whale Conservation Areas, as well as through marine conservation planning. The Habitat Management Program supports fish and fish habitat management through the environmental assessment of marine project proposals, as well as follow-up compliance and environmental effects monitoring.

Fisheries and Oceans Canada is undergoing Fisheries Management Renewal, in support of sustainable fisheries and aquaculture management. Fisheries Management Renewal is a package of program renewal undertakings that promote predictability, stability and transparency, and strong and healthy fisheries resources. The renewal is being implemented incrementally, in a manner consistent with constitutional protection provided to Aboriginal and treaty rights and consistent with international fisheries treaties, and with recognition that fishery resources are important to Canadians in many ways (Aboriginal fisheries, commercial fisheries, recreational fisheries, conservation, tourism). Other fisheries management initiatives supported by the Department include collaboration with fish harvesters in their efforts toward achieving sustainability eco-certification, as well as increased international cooperation on the management, enforcement, and trade measures for the reduction of illegal, unreported, and unregulated fishing and over-fishing on the high seas.

Last, the Department delivers programs and services in support of aquatic species at risk and marine emergency preparedness. Recovery Plans for at risk aquatic species continue to be developed, including the protection of species and their habitat from further harm through the development of protection measures and mitigation strategies. The Department is committed to working with industry to implement protection and mitigation measures. In support of marine emergency preparedness, the Canadian Coast Guard Marine Spill Contingency Plan defines the scope and framework within which the Coast Guard is prepared for and responds to a marine enviornmental emergency. The Department also supports response to an environmental emergency through participation on Environment Canada's Regional Environmental Emergency Team. The team consists of representatives from various government agencies (at all levels of government) that provide advice on environmental emergency response, based on their respective expertise, using a 'one window approach'.

REFERENCES

Abrahamson, A., Brandt, I., Brunström, B., Sundt, R.C., and Jorgensen, E.H. 2008. Monitoring contaminants from oil production at sea by measuring gill EROD activity in Atlantic cod (*Gadus morhua*). Environmental Pollution. 153:169-175

Addison, R.F. 1992. Detecting the effects of marine pollution. IN Science Review 1990 & '91. Bedford Institute of Oceanography, Dartmouth, Nova Scotia. 9-12.

Ainslie, M.A., deJong, C.A.F., Dol, H.S., Blacquiere, G. and Marasini, C. 2009. TNO Report TNO-DV2009 C085. The Netherlands Ministry of Transport, Public Works and Water Affairs: Directorate-General for Water Affairs. 110pp.

Albikovskaya, L.K. 1982. Distribution and abundances of Atlantic wolffish, spotted wolffish, and northern wolffish in the Newfoundland area. NAFO Sci. Coun. Studies. 3:29-32.

Altin, D., Frost, T.K., and Nilssen, I. 2008. Approaches for derivation of environmental quality criteria for substances applied in risk assessment of discharges from offshore drilling operations. Integrated Environmental Assessment and Management. 4:204-214.

AMEC. 2006. Revision of the physical environmental assessment for Deep Panuke production site - oceanographic component: produced water, cooling water, drilling wastes. Report prepared by AMEC for Jacques Whitford. 50pp.

Annis, E.R. 2005. Temperature effects on the vertical distribution of lobster postlarvae (*Homarus americanus*). Limnology and Oceanography. 50:1972-1982.

Anderson, M.R., Rivkin, R.B., and Warren, P. 2000. The influence of produced water on natural populations of marine bacteria. IN Proceedings of the 27th Annual Toxicity Workshop: October 1-4, 2000, St. John's, Newfoundland. Penney, K.C., Coady K.A., Murdoch, M.H., Parker, W.R., and Niimi, A.J. (eds.). Can. Tech. Rep. Fish. Aquat. Sci. 2331. 91-98.

Andrade, Y. and Loder, J.W. 1997. Convective descent simulations of drilling discharges on Georges and Sable Island Banks. Can. Tech. Rep. Hydrogr. Ocean Sci. 185. vi + 83 pp.

Andrews, C.D., French, B., Fancey, L., Guiney, J., and Payne J.F. 2004. Chronic toxicity study on snowcrab exposed to drilling fluid being used on the Grand Banks. IN Proceedings of the 31st Annual Toxicity Workshop: October 24-27, 2004, Charlottetown, Prince Edward Island. Burridge, L.E., Haya K., and Niimi, A.J. (eds.). Can. Tech. Rep. Fish. Aquat. Sci. 2562. 138pp.

Andrews, C.D., Guiney J., Fancey, L.L., and Lee, K. 2007. Assessment of the effects of the oil-well drilling waste barite on fish health. IN Proceedings of the 33rd Annual Aquatic Toxicity Workshop. October 1-4, 2006, Jasper, Alberta. Munsaon, B.A., Froese, J.M.W., Ferone, J-M., and Burridge, L.E. (eds.). Can. Tech. Rep. Fish. Aquat. Sci. 2746: xiv + 114 pp.

Andrews, C.D., Payne, J., Fancey, L., Hanlon, J., and Lee K. 2009. Potential of produced water discharges to affect fish health. International Produced Water Conference, Environmental Risks and Advances in Mitigation Technologies, October 17-18, 2007, St. John's, Newfoundland. Environmental Studies Funds Report. 43pp.

API (American Petroleum Institute). 2009. Analysis of U.S. Spillage. API Publication No. 356. American Petroleum Institute, Washington, D.C. 71pp.

Armsworthy, S.L., Cranford, P.J., Lee, K., and King, T. 2005. Chronic effects of synthetic drilling mud on Sea scallops (*Placopecten magellanicus*). IN Offshore Oil and Gas Environmental Effects Monitoring: Approaches and Tecnhologies. Armsworthy, S.L., Cranford, P.J., and Lee K. (eds.). Battelle Press, Columbus, Ohio. 243-265.

ASA (Applied Science Associates, Inc.). 2009. MUDMAP. Website <www.dredgemap.com /mudmap/mudmap.htm> cited (19 October 2010).

ASCE (American Society of Civil Engineers). 1996. State-of-the-art review of modeling transport and fate of oil spills. Journal of Hydraulic Engineering. 122:594-609.

ASMFC (Atlantic States Marine Fisheries Commission). 2009. Terms of Reference & Advisory Report for the American Lobster Stock Assessment Peer Review. Stock Assessment Peer Review Report No. 09-01 of the Atlantic States Marine Fisheries Commission.

Atema, J., Leavitt, D.F., Barshaw, D.E., and Cuomo. M.C. 1982. Effects of drilling muds on behaviour of the American lobster, *Homarus americanus,* in water column and substrate exposures. Canadian Journal of Fisheries and Aquatic Sciences. 39:675-690.

Atlas, R.M., 1984. Petroleum Microbiology. Macmillan Publishing Company, New York, U.S.A. 355pp.

Atlas, R.M. 1995. Petroleum biodegradation and oil spill bioremediation. Marine Pollution Bulletin. 31:178-182.

Atlas, R.M. and Bartha, R. 1992. Hydrocarbon biodegradation and oil-spill bioremediation. Advances in Microbial Ecology. 12:287-338.

Avens, L., Taylor, J.C., Goshe, L.R., Jones, T.T., and Hastings, M. 2009. Use of skeletochronological analysis to estimate age of leatherback sea turtles *Dermochelys coriacea* in the western North Atlantic. Endangered Species Research. 8:165-177.

Ayers, R.C. and M. Parker. 2001. Produced Water Waste Management. Canadian Association of Petroleum Producers (CAPP) Publication. Calgary, Alberta. 59pp.

Azarowicz, R.M. 1973. Microbial Degradation of Petroleum. U.S. Patent 3,769,164.

Azetsu-Scott, K., Yeats P., Wohlgeschaffen G., Dalziel J., Niven S., and Lee K. 2007. Precipitation of heavy metals in produced water: Influence on contaminant transport and toxicity. Marine Environmental Research. 63:146-167.

Baird, P.H. 1994. Black-legged Kittiwake (*Rissa tridactyla*). IN The Birds of North America, No. 92. Poole, A. and Gill, F. (eds.). The Birds of North America, Inc., Philadelphia, Pennsylvania.

Bakke, F.T., Gray J.S., and Reiersen L.O. 1990. Monitoring in the vicinity of oil and gas platforms: environmental status in the Norwegian sector in 1987-1989. IN Proceedings of the U.S. Environmental Protection Agency's First International Symposium on Oil and Gas Exploration on Production Waste Management Practices. September 10-13, 1990, New Orleans, Louisiana. 523-633.

Barlow, M.J. and Kingston, P.F. 2001. Observation on the effect of barite on gill tissues on the suspension feeder *Cerastoderma edule* (Linné) and the deposit feeder *Macoma balthica* (Linné). Marine Pollution Bulletin. 42:71-76.

Barth, T. 1991. Organic acids and inorganic ions in waters from petroleum reservoirs, Norwegian continental shelf: a multivariate statistical analysis and comparison with American reservoir formation waters. Applied Geochemistry. 6:1-15.

Bartha, R. 1986. Biotechnology of petroleum pollutant biodegradation. Microbial Ecology. 12:155-172.

Bartol S. and Musick J. 2003. Sensory biology of sea turtles. IN The Biology of Sea Turtles, Vol 2. Lutz, P.L., Musick, J.A, and Wyneken, J. (eds). CRC Press, Boca Raton, Florida. 79-102.

Battelle. 1994. Environmental assessment studies in the Gulf of Thailand. Phase II. Impact of processing activities and produced water discharges at Platong central processing platform. Report to Unocal Thailand Ltd., Bangkok, Thailand.

Baum, J.K., Myers, R.A., Kehlet, D.G., Worm, B., Harley, S.J., and Doherty, P.A. 2003. Collapse and conservation of shark populations in the Northwest Atlantic. Science. 299:389-392.

Baumgartner, D.J., Frick, W.E., and Roberts, P.J.W. 1994. Dilution models for effluent discharges (3rd Ed). U.S. Environmental Protection Agency Report No. EPA/600/R-94/086. U.S. Environmental Protection Agency, Newport, Oregon. Website <www.environmental-engineer.com/docs/dos_plumes/rsb_um_plumes.pdf> (cited 20 October 2010). 199pp.

Baumgartner, M.F., Cole, T.V.N., Campbell, R.G., Teegarden, G.J., and Durbin, E.G. 2003. Associations between North Atlantic right whales and their prey, *Calanus finmarchicus*, over diel and tidal time scales. Marine Ecology Progress Series. 264:155-166.

Beamish, F.W.H. 1966. Vertical migration by demersal fish in the Northwest Atlantic. Journal of the Fisheries Research Board of Canada. 23:109-139.

Beansland, D., Branton, R., and Mohen, R. 2000. Status of Monkfish in 4VWX5Zc. DFO Can. Stock Assess. Sec. Res. Doc. 2000/143.

Beauchamp, J., Bouchard, H., de Margerie, P., Otis, N., and Savaria, J.Y. 2009. Recovery Strategy for the blue whale (*Balaenoptera musculus*), Northwest Atlantic population, in Canada. DFO Species at Risk Strategy Series. Fisheries and Oceans Canada, Ottawa.

Beckett J.S. 1972. Biology of swordfish, *Xiphias gladius* L., in the Northwest Atlantic Ocean. NOAA Tech. Rep. NMFS SSRF-675. 103-106.

Begg, G.A., Hare, J.A., and Sheehan, D.D. 1999. The role of life history parameters as indicators of stock structure. Fisheries Research. 43:141-163.

Berry, J.A. and Wells, P.G. 2004a. Integrated fate modeling for exposure assessment of produced water on the Sable Island Bank (Scotian Shelf, Canada). Environmental Toxicology and Chemistry. 23:2483-2493.

Berry, J.A. and Wells, P.G. 2004b. Environmental modeling of produced water dispersion with implications for environmental effects monitoring design. IN Offshore Oil and Gas Environmental Effects Monitoring: Approaches and Tecnhologies. Armsworthy, S.L., Cranford, P.J., and Lee K. (eds.). Battelle Press, Columbus, Ohio. 111-129.

Bigelow, H.B. 1926. Plankton of the offshore waters of the Gulf of Maine. Bulletin of the U.S. Bureau of Fisheries, Vol. XL, Part II. U.S. Government Printing Office, Washington, D.C.

Bigelow, H.B. and Schroeder, W.C. 1953. Fishes of the Gulf of Maine. Fishery Bulletin. 74:1-577.

Billiard, S.M., Meyer, J.N., Wassenberg, D.M., Hodson, P.V., and Di Giulio, R.T. 2008. Nonadditive effects of PAHs on early vertebrate development: mechanisms and implications for risk assessment. Toxicological Sciences. 105:5-23.

Birdsall, A., Buchanan, R.A., Lewbel, G.S., Duval, W.S., McDonald, J.W., Thomas, D.J., Hutcheson, M.S., Greene, G.D., and Johnston, C.S. 1985. Effects monitoring strategies and programs for Canada's east coast. Environmental Studies Research Funds Report (ESRF) Series No. 005. 88pp.

Bisagni, J.J. 2000. Estimates of vertical heat flux and stratification from Southern Georges Bank, interannual variability, 1985–1995. Continental Shelf Research. 20:211-234.

Bisagni, J.J. 2003. Seasonal variability of nitrate supply and potential new production in the Gulf of Maine and Georges Bank regions. Journal of Geophysical Research. 108:8015. 22pp.

Bisagni, J.J. and Smith, P.C. 1998. Eddy-induced flow of Scotian Shelf water across the Northeast Channel, Gulf of Maine. Continental Shelf Research. 18:515-539.

Black, G.A.P., Mohn, R.K., Robert, G., and Tremblay, M.J. 1993. Atlas of the biology and distribution of the sea scallop Placopecten magellanicus and Iceland scallop Chlamys islandica in the Northwest Atlantic. Can. Tech. Rep. Fish. Aquat. Sci. 1915. 40pp.

Blenkinsopp S., Sergy, G., Wang, Z., Fingas, M.F., Foght, J., and Westlake, D.W.S. 1995. Oil spill bioremediation agents-Canadian efficacy test protocols. IN Proceedings of the 1995 International Oil Spill Conference. American Petroleum Institute, Washington D.C. American Petroleum Institute Publication No. 4620. 91-96.

Block, B.A.., Dewar, H., Blackwell, S.B., Williams, T.D., Prince, E.D., Farwell, C.J., Boustany, A., Teo, S.L.H., Seitz, A., Walli, A., and Fudge, D. 2001. Migratory movements, depth preferences, and thermal biology of Atlantic bluefin tuna. Science. 293:1310-1314.

Block, B.A., Teo, S.L.H., Walli, A. Boustany, A., Stokesbury, M.J.W., Farwell, C.J., Weng, K.C., Dewar, H., and Williams, T.D. 2005. Electronic tagging and population structure of Atlantic bluefin tuna. Nature. 434:1121-1127.

Booth, J.E. 1990. Use of shallow seismic data in relief well planning. World Oil 210 (5): 39-43.

Boothe, P.N. and Presley, B.J. 1989. Trends in sediment trace element concentrations around six petroleum drilling platforms in the Northwest Gulf of Mexico. IN Drilling Wastes. Proceedings of the 1988 International Conference on Drilling Wastes. April 5-8, 1989, Calgary, Alberta. Engelhardt, F.R., Ray, J., and Gillam A.H. (eds). Elsevier. 3-22.

Borgund, A.E. and Barth, T. 1994. Generation of short-chain organic acids from crude oil by hydrous pyrolysis. Organic Geochemistry. 21:943-952.

Børseth, J.F. and Tollefsen K.-E. 2004. Water column monitoring 2003 – RF summary report. Report RF-2004/039. Rogaland Research, Stavanger, Norway.

Bothamley, M. 2004. Offshore processing options vary widely. Oil & Gas Journal. 102:47-55.

Bothner, M.H. Rendigs, R.R., Campbell E.Y., Doughton, M.W., Parmenter, C.M., O'Dell, C.H., Dilisio, G.P., Johnson, R.G., Gillison, J.R., and Rait, N. 1985. The Georges Bank monitoring program: Analysis of trace metals in bottom sediments during the third year of monitoring. Final report submitted to the US MMS us DOI, USCG, Woods Hole, Massachussetts. 99pp.

Boudreau, P.R., Gordon, D.C.Jr., Harding, G.C., Loder, J.W., Black, J., Bowen, W.D., Campana, S., Cranford, P.J., Drinkwater, K.F., Van Eeckhaute, L., Gavaris, S., Hannah, C.G., Harrison, G., Hunt, J.J. McMillan, J., Melvin, G.D., Milligan, T.G., Muschenheim, D.K., Neilson, J.D., Page, F.H., Pezzack, D.S., Robert, G., Sameoto, D., and Stone, H. 1999. The Possible Environmental Impacts of Petroleum Exploration Activities on the Georges Bank Ecosystem. Can. Tech. Rep. Fish. Aquat. Sci. 2259. vi + 106pp.

Boufadel, M.C., Du, K., Kaku, V., and Weaver, J. 2007. Lagrangian simulation of oil droplets transport due to regular waves. Environmental Modelling & Software. 22:978-986.

Bourne, N. 1964. Scallops and the offshore fishery of the Maritimes. Fish. Res. Board of Can. Bull. No. 145.

Bowen, W.D., Lawson, J.W., and Beck, B. 1993. Seasonal and geographic variation in the species composition and size of prey consumed by grey seals (*Halichoerus grypus*) on the Scotian Shelf. Canadian Journal of Fisheries and Aquatic Sciences. 50:1768-1778.

Bowen, W.D., Ellis, S.L., Iverson, S.J., and Boness, D.J. 2003. Maternal and newborn life history traits during periods of contrasting population trends: Implications for explaining the decline of harbour seals (*Phoca vitulina*), on Sable Island. Journal of Zoology, London. 261:155-163.

Bowen, W.D., McMillan, J.I., Lidgard, D., and Blanchard, W. 2007. Continued reduction in population growth rates of grey seals at Sable Island. DFO. Can. Sco. Advis. Sec. Res. Doc. 2007/087.

Braddock, J.F., Lindstorm, J.E., and Brown, E.J. 1995. Distribution of hydrocarbon-degrading microorganisms in sediments from Prince William sound, Alaska, following the Exxon Valdez spill. Marine Pollution Bulletin. 30:125-132.

Bragg, J.R., Prince, R.C., Harner, E.J., and Atlas, R.M. 1994. Effectiveness of bioremediation for the Exxon-Valdez Oil-Spill. Nature. 368:413-418.

Brand, A.R. 2006. Scallop ecology: distributions and behaviour. IN Scallops: Biology, Ecology and Aquaculture, Second Edition. Shumawy S.E. and Parsons, G.J. (eds). Elsevier, New York. 651-744.

Brandsma, M.G. 2001. Near-field produced water plume, Platform Irene. Report submitted to Arthur D. Little, Inc., Santa Barabara, California (Report prepared by Brandsma Engineering).

Brandsma M.G. 2003. Automatic validation of the offshore operators committee discharge model and application to predicting drilling solids accumulation on the sea floor. Spill Science & Technology Bulletin. 8:549-559.

Brandsma, M.G. and Sauer, T.C. 1983. Mud Discharge Model – Report and User's Guide. Exxon Production Research Company, Huston, Texas. 140pp.

Brandsma, M.G. and Smith J.P. 1996. Dispersion modeling perspectives on the environmental fate of produced water discharges. IN Produced Water 2. Environmental Issues and Mitigation Technologies (Environmental Science Research, Volume 52). Reed, M. and Johnsen, S. (eds.). Plenum Press, New York. 215-224.

Brandsma, M.G., Davis, I.R., Ayers, R.C.Jr, and Sauer, T.C.Jr. 1980. A computer model to predict the short-time fate of drilling discharges in the marine environment. IN Proceedings Symposium on Research on Environmental Fate and Effects of Drilling Fluids and Cuttings, Lake Buena Vista, Florida. American Petroleum Institute, Washington, D.C. 588-608.

Brawn V.M. 1961. Reproductive behaviour of the cod (*Gadus callarias* L.). Behaviour. 18:177-198.

Breed, G.A., Jonsen, I.D., Myers, R.A., and Bowen, W.D. 2009. Sex specific, seasonal foraging tactics of adult grey seals (*Halichoerus grypus*) revealed by state-space analysis. Ecology. 90:3209-3221.

Breeze, H., D.G. Fenton, R.J. Rutherford, and M.A. Silva. 2002. The Scotian Shelf: An Ecological Overview for Ocean Planning. Can. Tech. Rep. Fish. Aquat. Sci. 2393. x + 259pp.

Brink, K.H., Limeburner, R., and Beardsley, R.C. 2003. Properties of flow and pressure over Georges Bank as observed with near-surface drifters. Journal of Geophysical Research. 108:8001. 17pp.

Brodziak, J.T. 1995. Long-finned squid. IN Status of the Fishery Resources off the Northeastern United States for 1994. Conservations and Utilization Division, Northeast Fisheries Science Center (ed.). NOAA Tech. Mem. NMFS-NE-108.

Brodziak, J.T. 2005. Essential fish habitat source document: Haddock, *Melanogrammus aeglefinus*, life History and habitat characteristics, 2nd ed. NOAA Tech. Mem NMFS-NE-196. 74pp.

Brodziak, J.T. and Macy, W.K.. 1996. Growth of long-finned squid, Loligo pealei, in the Northwest Atlantic. Fishery Bulletin. 94:212-236.

Brown, R.G.B., Nettleship, D.N., Germain, P., Tull, C.E., and Davis, T. 1975. Atlas of eastern Canadian seabirds. Canadian Wildlife Service, Ottawa, Ontario.

Brown, R.G.B. 1986. Revised atlas of eastern Canadian seabirds. I. Shipboard surveys. Canadian Wildlife Service, Ottawa, Ontario.

Brown, S.K., Mahon, R., O'Boyle, R., Zwanenburg, K. Buja, K., Claflin, L., Atkinson, B., Howell, G., Sinclair, M., and Monaco, M. 1996. East coast of North America groundfish: initial explorations of biogeography and species assemblages. Strategic Environmental Assessments Division, National Oceanic and Atmospheric Administration, Silver Spring, Maryland and Marine Fish Division, Department of Fisheries and Oceans, Dartmouth, Nova Scotia.

Brown, H., Bollens, S.M., Madin, L,P., and Horgan, E.F. 2005. Effects of warm water intrusions on populations of macrozooplankton on Georges Bank, Northwest Atlantic. Continental Shelf Research. 25:143-156.

Brown, M.W., Fenton, D., Smedbol, K., Merriman, C., Robichaud-Leblanc, K., and Conway, J.D. 2009. Recovery Strategy for the North Atlantic Right Whale (*Eubalaena glacialis*) in Atlantic Canadian Waters [Final]. Species at Risk Act Recovery Strategy Series. Fisheries and Oceans Canada, Ottawa.

Bruno, I., Costas, G., González, C., and Paz, X. 2000. Feeding chronology of yellowtail flounder (*Limanda feruginea)* and American plaice (*Hippoglossoides platessoides)* on Grand Bank (NAFO Division 3N). NAFO Sci. Coun. Studies 33. 103–116.

Buckley, L.J. and Durbin, E.G. 2006. Seasonal and inter-annual trends in the zooplankton prey and growth rate of Atlantic cod (*Gadus morhua*) and haddock (*Melanogrammus aeglefinus*) larvae on Georges Bank. Deep-Sea Research II 53:2758-2770.

Buist, I., Trudel, K., Morrison, J., and Aurand, D. 1995. Laboratory studies of the properties of in-situ burn residues. IN Proceedings of the 1995 International Oil Spill Conference. American Petroleum Institute, Washington D.C. 4245-4252.

Buist, I. Potter, S., Mullin, J., Lane, J., Devitis, D., Schmidt, B., Stahovec, J., Urban, B., and Moffatt, C. 2005. Fire resistant booms tested in flames at Ohmsett. IN Proceedings of the 2005 International Oil Spill Conference. American Petroleum Institute, Washington D.C. 9456-9461.

Buist, I., Potter, S., Nedwed, T., and Mullin, J. 2008. Herding agents thicken oil spills in drift ice to facilitate in situ burning: A new trick for an old dog. IN Proceedings of the 2008 International Oil Spill Conference. American Petroleum Institute, Washington D.C. 673-680.

Burns, K.A., Codi, S., Furnas, M., Heggie, D., Holdway, D., King, B., and McAllister, F. 1999. Dispersion and fate of produced formation water constituents in an Australian Northwest Shelf Shallow Water Ecosystem. Marine Pollution Bulletin. 38:593-603.

Butman, B. and Beardsley, R.C. 1987. Physical oceanography. IN Georges Bank. Backus, R.H. and D.W. Bourne, D.W. (eds.). MIT Press, Cambridge, Massachusetts. 88-98.

Butman, B., Loder, J.W., and Beardsley, R.C. 1987. The seasonal mean circulation: observation and theory. IN Georges Bank. Backus, R.H. and D.W. Bourne, D.W. (eds.). MIT Press, Cambridge, Massachusetts. 125-138.

Cadrin, S.X. 2003. Stock structure of yellowtail flounder off the northeastern United States. University of Rhode Island Doctoral Dissertation.

Cadrin, S.X. 2006. Yellowtail flounder tagging study – 2006 Annual Report. Northeast Consortium Annual Report.

Cadrin, S.X. and Moser, J. 2006. Partitioning on-bottom and off-bottom behaviour: A case study with yellowtail flounder off New England. International Council for the Exploration of the Sea Report CM 2006/Q. 14pp.

Cadrin, S.X., Westwood, A., Alade, L., Keith, N., Rountree, R., Martins, C., Kessler, R., Jones, D., Valliere, A., King, J., Boardman, J., Stone, H., and New England Fishermen. 2004. Movement of yellowtail flounder: A cooperative tagging study. Ninth Flatfish Biology Conference, December 1-2, 2004, West Brook, Connecticut. NEFSC Ref. Doc. 04-13.

Caldwell, J. and Dragoset, W. 2000. A brief overview of seismic air-gun arrays. The Leading Edge. August 2000:898-902.

Cameron, P., Berg, J.Dethlefsen, V., and Von Westernhagen, H. 1992. Developmental defects in pelagic embryos of several flatfish species in the southern North Sea. Netherlands Journal of Sea Research. 29:239-256.

Campana, S.E., Gibson, A.J.F., Fowler, M., Dorey, A., and Joyce, W. 2010. Population dynamics of porbeagle in the northwest Atlantic, with an assessment of status to 2009 and projections for recovery. Collect. Vol. Sci. Pap. ICCAT. 65:2109-2182.

Candler, J.E., Hoskin, S., Churan, M., Lai, C.W., and Freeman, M. 1995. Seafloor mapping for synthetic-based mud discharge in the Western Gulf of Mexico. Paper presented at the U.S.EPA Exploration and Production Environmental Conference, March 27-29, Houston, Texas. 27-29.

Capuzzo, J.M. 1988. Physiological effects of a pollution gradient – introduction. Marine Ecology Progress Series. 46:111.

Cargnelli, L., Griesbach, S., and Morse W. 1999. Essential fish habitat source document: Atlantic halibut, *Hippoglossus hippoglossus*, life history and habitat characteristics. NOAA Tech. Memo. NMFS-NE-125. 26pp.

Carls, M.G., Heintz, R.A., Marty, G.D., and Rice, S.D. 2005. Cytochrome P4501A induction in oil-exposed pink salmon *Oncorhynchus gorbuscha* embryos predicts reduced survival potential. Marine Ecology Progress Series. 301:253-265.

Carruthers, E.H., Neilson, J.D., Waters, C., and Perley, P. 2005. Long term changes in the feeding of *Pollachius virens* on the Scotian Shelf: responses to a dynamic ecosystem. Journal of Fish Biology. 66:327-347.

Carter, J.A. and Steele, D.H. 1982. Stomach contents of immature lobsters (*Homarus americanus*) from Placentia Bay, Newfoundland. Canadian Journal of Zoology. 60:337-347.

Carter, J., MacGregor, C., Tidmarsh, G., Chandler, P., Parsons, J., and Bonke, C. 1985. Monitoring programs associated with the Uniacke G-72 gas/condensate blowout on the Scotian Shelf. IN Proceedings of the 8th Arctic and Marine Oilspill Program (AMOP) Technical Seminar. Environment Canada, Ottawa, Ontario. 403-422.

Casey, J. and Myers, R.A. 1998. Near extinction of a large, widely distributed fish. Science. 281:690-692.

Casper, B.M., Domingo, A., Gaibor, N., Heupel, M.R., Kotas, E., Lamónaca, A.F., Pérez-Jimenez, J.C., Simpfendorfer, C., Smith, W.D., Stevens, J.D., Soldo, A., and Vooren, C.M. 2005. *Sphyrna zygaena*. IN IUCN 2009, IUCN Red List of Threatened Species, Version 2009.2. Website <www.iucnredlist.org> (cited 2 February 2010).

Cassoff, R.M., Campana, S.E., and Myklevoll, S. 2007. Changes in baseline growth and maturation parameters of Northwest Atlantic porbeagle, Lamna nasus, following heavy exploitation. Canadian Journal of Fisheries and Aquatic Sciences. 64:19-29.

CCG (Canadian Coast Guard). 2009. Marine Spills Contingency Plan. Website <http://www.ccg-gcc.gc.ca/eng/CCG/ER_National_Response_Plan> (cited November 23, 2009).

CCG and USCG (Canadian Coast Guard and United States Coast Guard). 2009. Canada–United States Joint Marine Pollution Contingency Plan. Website <http://www.ccg-gcc.gc.ca/folios/00025/docs/canadaus_pub-eng.pdf> (cited November 23, 2009). 21pp.

CETAP (Cetacean and Turtle Assessment Program). 1982. A characterization of marine mammals and turtles in the mid- and North-Atlantic area of the U.S. outer continental shelf, Rep. No. NYIS PB83-243289. Final Report to Bureau of Land Management, Springfield, Virginia.

Chardine, J.W. 2000. Census of Northern Gannet colonies in the Atlantic Region in 1999. Tech. Report No. 361. Canadian Wildlife Service, Atlantic Region.

Chase, D. 1994. CDFATE user's manual. Report prepared for U.S. Army of Engineers Waterways Experiment Section, Vicksburg, Mississippi (Report prepared by Don Chase, Department of Civil & Environmental Engineering, University of Dayton, Dayton, Ohio). Website <http://el.erdc.usace.army.mil/elmodels/pdf/cdfate.pdf> (cited 20 October 2010). 64pp.

Chen, C., Xu, Q., Beardsley, R.C., and Franks, P.J.S. 2003a. Model study of the cross-frontal water exchange on Georges Bank: A three-dimensional Lagrangian experiment. Journal of Geophysical Research. 108:3142.

Chen, C., Schlitz, R.J., Lough, R.G., Smith, K.W., Beardsley, R.C., and Manning, J.P. 2003b. Wind-induced, cross-frontal exchange on Georges Bank: A mechanism for early summer on-bank biological particle transport. Journal of Geophysical Research. 108:8011. 11pp.

Chen, Z., Zhan, C.S., Lee, K., Li, Z., and Boufadel, M.C. 2008. Modeling of oil drolet kinetics under breaking waves. IN Proceedings of the NATO CCMS Workshop on Oil Spill Response, October 11-13, 2006, Dartmouth, Nova Scotia. Davidson, W.F., Lee, K., and Cogswell, A. (eds). Springer Science, The Netherlands. 221-236.

Christian, J.R., Mathieu, A., Thompson, D.H., White, D., and Buchanan, R.A. 2003. Effect of seismic energy on snow crab (*Chionoecetes opilio*). Environmental Studies Research Funds Report No. 144. Environmental Studies Research Funds, Calgary, Alberta. 106pp.

Churchill, J.H., Manning, J.P., and Beardsley, R.C. 2003. Slope water intrusions onto Georges Bank. Journal of Geophysical Research. 108:8012. 16pp.

Clark, D. and Emberley, J. 2009. Update of the 2008 summer Scotian Shelf and Bay of Fundy research vessel survey. DFO Can. Sci. Advis. Sec. Res. Doc. 2009/017.

Clark, D., Emberley, J., Clark, C., and Peppard, B. 2010. Update of the 2009 Summer Scotian Shelf and Bay of Fundy Research Vessel Survey. DFO Can. Sci. Advis. Sec. Res. Doc. 2010/008.

Clark, C.W. and Gagnon, G.C. 2006. Considering the Temporal and Spatial Scales of Noise Exposures from Seismic Surveys on Baleen Whales. IWC/SC/58/E9 (Submitted to Scientific Committee, International Whaling Commission). 9pp.

CNLOPB (Canada-Newfoundland and Labrador Offshore Petroleum Board). 2010. Spill Statistics Summary (1997-2009). Website <www.cnlopb.nl.ca/pdfs/spill/sumtab.pdf > (cited 22 October 2010). 1pp.

CNSOPB (Canada-Nova Scotia Offshore Petroeum Board). 2008. Investigation report: monoethylene glycol (MEG) spill January 2006, Sable Offshore Energy Project. Report date 6/27/2008. Website <www.cnsopb.ns.ca/pdfs/MEG_Spill_2006.pdf> (cited 25 October 2010). 13pp.

CNSOPB (Canada–Nova Scotia Offshore Petroleum Board). 2009. Guideline for the Reporting and Investigation of Incidents. Website <http://www.cnsopb.ns.ca/pdfs/incrptgl.pdf > (cited November 23, 2009). 29pp.

CNSOPB (Canada-Nova Scotia Offshore Petroeum Board). 2010. Spills to the Sea. Website <www.cnsopb.ns.ca/environment_incident_statistics.php> (cited 27 October 2010).

Cochrane, N.A. 2005. Near-bottom ocean acoustic observations in the Scotian Shelf Gully Marine Protected Area during an exploration seismic survey. IN Acoustic Monitoring and Marine Mammal Surveys in the Gully and Outer Scotian Shelf Before and During Active Seismic Programs. Environmental Studies Research Funds Report No.151. Lee, K., Bain, H., and Hurley, G.V. (eds). Environmental Studies Research Funds, Calgary, Alberta. 75-88.

Cogswell, A.T., Kenchington, E.L.R., Lirette, C.G., MacIsaac, K., Best, M.M., Beazley, L.I., and Vickers, J. 2009. The current state of knowledge concerning the distribution of coral in the Maritime Provinces. Can. Tech. Rep. Fish. Aquat. Sci. 2855. v + 66 p.

Cohen, E.B. and Grosslein, M.D. 1987. Production on Georges Bank compared with other shelf ecosystems. IN Georges Bank. Backus, R.H. and Bourne, D.W. (eds). MIT Press, Cambridge, Massachusetts. 383-391.

Cohen, R.E. and Lough, R.G. 1983. Prey field of larval herring *Clupea harengus* on a continental shelf spawning area. Marine Ecology Progress Series. 10:211-222.

Colette, B.B. and Klein-MacPhee G (eds.). 2002. Bigelow and Shroeder's fishes of the Gulf of Maine, 3rd ed. Smithsonian Institution Press, Washington, D.C.

Colcomb, K., Peddar, M., Salt, D., and Lewis, A. 2005. Determination of the limiting oil viscosity for chemical dispersion at sea. IN Proceedings of the 2005 International Oil Spill Conference. American Petroleum Institute, Washington D.C. 11506-11511.

Collie, J.S. 1987. Food consumption of yellowtail flounder in relation to production of its benthic prey. Marine Ecology Progress Series. 36:205-213.

Collie, J.S., Escanero, G.A., and Valentine, P.C. 1997. Effects of bottom fishing on the benthic megafauna of Georges Bank. Marine Ecology Progress Series. 155:159-172.

Collie J.S., Escanero, and P.C. Valentine. 2000. Photographic evaluation of the impacts of bottom fishing on benthic epifauna. ICES Journal of Marine Science. 57:987-1001.

Collie, J.S., Hermsen, J.M., Valentine, P.C., and Almeida, F.P. 2004. Effects of fishing on gravel habitats: assessment and recovery of benthic megafauna on Georges Bank. IN Benthic Habitats and the Effects of Fishing. Barnes, P. and Thomas, J. (eds.). American Fisheries Society, Bethesda, Maryland.

Collie, J.S., Hermsen, J.M., and Valentine, P.C. 2009. Recolonization of gravel habitats on Georges Bank (Northwest Atlantic). Deep Sea Research II. 56:1847-1855.

Collins, A.G. 1975. Geochemistry of Oilfield Waters. Elsevier Scientific Publishers, New York. 496pp.

Colton, J.B.Jr., Temple, R.F., and Honey, K.A. 1962. The occurrence of oceanic copepods in the Gulf of Maine–Georges Bank area. Ecology. 43:66-171.

Conant, T.A., Dutton, P.H., Eguchi, T., Epperly, S.P., Fahy, C.C., Godfrey, M.H., MacPherson, S.L., Possardt, E.E., Schroeder, B.A., Seminoff, J.A., Snover, M.L., Upite, C.M., and Witherington, B.E. 2009. Loggerhead sea turtle *(Caretta caretta)* 2009 status review under the U.S. Endangered Species Act. Report of the Loggerhead Biological Review Team to the National Marine Fisheries Service.

Cooper, R.A. and Uzmann, J.R. 1980. Ecology of juvenile and adult homarus. IN The Biology and Management of Lobsters, Vol 2: Ecology and Management. Cobb, J.S. and Phillips, B.F. (eds.). Academic Press, New York. 390pp.

COSEWIC (Committee on the Status of Endangered Wildlife in Canada). 2000. COSEWIC assessment and status report on the Atlantic wolffish *Anarhichas lupus* in Canada. Committee on the Status of Endangered Wildlife in Canada. Ottawa.

COSEWIC (Committee on the Status of Endangered Wildlife in Canada). 2001. COSEWIC assessment and status report on the leatherback turtle *Dermochelys coriacea* in Canada. Committee on the Status of Endangered Wildlife in Canada. Ottawa

COSEWIC (Committee on the Status of Endangered Wildlife in Canada). 2002. COSEWIC assessment and update status report on the blue whale *Balaenoptera musculus* in Canada. Committee on the Status of Endangered Wildlife in Canada. Ottawa.

COSEWIC (Committee on the Status of Endangered Wildlife in Canada). 2003a. COSEWIC assessment and status report on the cusk, *Brosme brosme* in Canada. Committee on the Status of Endangered Wildlife in Canada. Ottawa.

COSEWIC (Committee on the Status of Endangered Wildlife in Canada). 2003b. COSEWIC assessment and update status report on the North Atlantic right whale *Eubalaena glacialis* in Canada. Committee on the Status of Endangered Wildlife in Canada. Ottawa.

COSEWIC (Committee on the Status of Endangered Wildlife in Canada). 2004. COSEWIC assessment and status report on the porbeagle shark *Lamna nasus* in Canada. Committee on the Status of Endangered Wildlife in Canada. Ottawa.

COSEWIC (Committee on the Status of Endangered Wildlife in Canada). 2005a. COSEWIC assessment and status report on the winter skate Leucoraja ocellata in Canada. Committee on the Status of Endangered Wildlife in Canada. Ottawa.

COSEWIC (Committee on the Status of Endangered Wildlife in Canada). 2005b. COSEWIC assessment and update status reported on the fin whale Balaenoptera physalus in Canada. Committee on the Status of Endangered Wildlife in Canada. Ottawa.

COSEWIC (Committee on the Status of Endangered Wildlife in Canada). 2006a. COSEWIC assessment and status report on the shortfin mako *Isurus oxyrinchus* (Atlantic population) in Canada. Committee on the Status of Endangered Wildlife in Canada. Ottawa.

COSEWIC (Committee on the Status of Endangered Wildlife in Canada). 2006b. COSEWIC assessment and status report on the blue shark *Prionace glauca* (Atlantic and Pacific populations) in Canada. Committee on the Status of Endangered Wildlife in Canada. Ottawa

COSEWIC (Committee on the Status of Endangered Wildlife in Canada). 2006c. COSEWIC assessment and status report on the white shark *Carcharodon carcharias* (Atlantic and Pacific populations) in Canada. Committee on the Status of Endangered Wildlife in Canada. Ottawa.

COSEWIC (Committee on the Status of Endangered Wildlife in Canada). 2006d. COSEWIC assessment and update status report on the harbour porpoise *Phocoena phocoena* (Northwest Atlantic population) in Canada. Committee on the Status of Endangered Wildlife in Canada. Ottawa.

COSEWIC (Committee on the Status of Endangered Wildlife in Canada). 2006e. COSEWIC assessment and update status report on the Sowerby's beaked whale *Mesoplodon bidens* in Canada. Committee on the Status of Endangered Wildlife in Canada. Ottawa.

COSEWIC (Committee on the Status of Endangered Wildlife in Canada). 2010 assessment and status report on the deepwater Redfish/Acadian redfish complex *Sebastes mentella* and *Sebastes fasciatus* in Canada. Committee on the Status of Endangered Wildlife in Canada. Ottawa. X + 80pp.

Cotter, R.C., Rail, J.-F., Boyne, A.W., Chaulk, K.G., Robertson, G.J., and Weseloh, D.V. 2010. Population status, distribution and trends of gulls and kittiwakes nesting in coastal Atlantic Canada and along the Great Lakes-St. Lawrence system of Ontario and Quebec. Canadian Wildlife Service Occasional Paper.

Couillard, C.M., Lee, K., Legare, B., and King, T.L. 2005. Effect of dispersant on the composition of the water-accommodated fraction of crude oil and its toxicity to larval marine fish. Environmental Toxicology and Chemistry. 24:1496-1504.

Courtenay, S.C., Boudreau, M., and Lee, K. 2009. Potential Impacts of Seismic Energy on Snow Crab. Environmental Studies Research Funds (ESRF) Report No. 178: NE22-4/178E-PDF. 181pp.

Cranford, P.J. 1995. Relationships between food quantity and quality and absorption efficiency in sea scallops *Placopecten magellanicus* (Gmelin). Journal of Experimental Marine Biology and Ecology. 189:123-142.

Cranford, P.J. 2006. Scallops and marine contaminants. IN Scallops: Biology, Ecology and Aquaculture (2nd Ed.). Shumway, S. and Parsons, J. (eds.). Elsevier Applied Science, London. 745-764.

Cranford, P.J. and Gordon, D.C.Jr. 1992. The influence of dilute clay suspensions on sea scallop (*Placopecten magellanicus*) feeding activity and tissue growth. Netherlands Journal of Sea Research. 30:107-120.

Cranford, P.J., Gordon, D.C.Jr., Lee, K., Armsworthy, S.L., and Tremblay, G.-H. 1999. Chronic toxicity and physical disturbance effects of water- and oil-based drilling fluids and some major constituents on adult sea scallops (*Placopecten magellanicus*). Marine Environmental Research. 48:225-256.

Cranford, P.J., Lee, K., Loder, J., Milligan, T.G., Muschenheim, D., and Payne, J. 2001. Scientific considerations and research results relevant to the review of the 1996 Offshore Waste Treatment Guidelines. Can. Tech Rep. Fish. Aquat. Sci. 2364. vi + 25 pp.

Cranford, P.J., Gordon, D.C.Jr., Hannah, C.G., Loder, J.W., Milligan, T.G., Muschenheim, K., and Shen, Y. 2003. Modelling potential effects of petroleum exploration drilling on northeastern Georges Bank scallop stocks. Ecological Modeling. 166:19-39.

Cranford, P.J., Armsworthy, S.L., McGee, S., King, T., Lee, K., and Tremblay, G.-H. 2005. Scallops as sentinel organisms for off-shore environmental effects monitoring. IN Offshore Oil and Gas Environmental Effects Monitoring: Approaches and Tecnhologies. Armsworthy, S.L., Cranford, P.J., and Lee K. (eds.). Battelle Press, Columbus, Ohio. 267-296.

CSA (Continental Shelf Associates, Inc.). 1986. Environmental monitoring program for Exploratory Well No. 1, Lease OCS-G 6613, East Breaks Area Block 166. Report prepared for Texaco U.S. 72pp.

CSA (Continental Shelf Associates, Inc.). 1993. Measurements of naturally occurring radioactive materials at two offshore production platforms in the northern Gulf of Mexico. Final report to the American Petroleum Institute, Washington, D.C.

Csanady, G.T. and Magnell, B.A. 1987. Mixing processes. IN Georges Bank. Backus, R.H. and Bourne, D.W. (eds.). MIT Press, Cambridge, Massachussetts. 163-169.

Curran, K.J., Wells, P.G., and Potter, A.J. 2006. Proposing a coordinated environmental effects monitoring (EEM) program structure for the offshore petroleum industry, Nova Scotia, Canada. Marine Policy. 30:400-411.

Cushing, D.H. 1990. Plankton production and year-class strength in fish populations: an update of the match/mismatch hypothesis. Advances in Marine Biology. 26:249-294.

Daan, R., Boou, K., Mulder, M., and Van Weerlee, E.M. 1996. Environmental effects of a discharge of drill cuttings contaminated with ester-based drilling muds in the North Sea. Environmental Toxicology and Chemistry. 15:1709-1722.

Dale, A.C., Ullman, D.S., Barth, J.A., and Hebert, D. 2003. The front on the northern edge of Georges Bank in Spring. Part I: Tidal and Subtidal Variability. Journal of Geophysical Research. 108:8009. 18pp.

Dalen, J. and Raknes, A. 1985. Scaring effects on fish from three-dimensional seismic surveys. Report No. FO 8504. Institute of Marine Research, P.O. Box 1870, N.5024 Bergen, Norway.

Dalen, J., Ona, E., Vold Soldal, A., and og Sætre, R. 1996. Seismiske undersøkeleser til havs: En vurdering av konsekvenser for fisk og fiskerier. *Fisken og Havet*, nr. 9 – 1996. 26 s.

Dalen, J., Dragsund, E., and Næss, A. 2007. Effects of seismic surveys on fish, fish catches and sea mammals. Report for Cooperation group - Fishery Industry and Petroleum Industry, Norway. DNV Energy Report - 2007-0512 rev 01. 33pp.

Danenberger, E.P. 1983. Georges Bank exploratory drilling (1981-1982): U.S. Department of the Interior, Minerals Management Service, North Atlantic District, Hyannis, Massachssetts. 20pp.

Davies, J.M., Addy, J.M., Blackman, R.A., Blanchards, J.R., Ferbrache, J.E., Moore, D.C., Sommerville, H.J., Whitehead, A., and Wilkinson, T. 1984a. Environmental effects of use of oil-based drilling muds in the North Sea. Marine Pollution Bulletin. 15:363-370.

Davies, J.M., Bell, J.S., and Houghton, C. 1984b. A comparison of the levels of hepatic aryl hydroxylase in fish caught close to and distant from North Sea oil fields. Marine Environmental Research. 14:23-45.

Davies, J.M., Bedbprpigj, D., Blackman, R.A., Applebee, J., Grogan, W., Parker, J.G., and Whitehead, A. 1988. The environmental effects of oil based mud drilling in the North Sea. Report prepared by the UKOOA/Government Working Group, United Kingdom.

Davis, C.S. 1984. Interaction of a copepod population with the mean circulation on Georges Bank. Journal of Marine Research. 42:573-590.

Davis, C.S. 1987. Zooplankton life cycles. IN Georges Bank. Backus, R.H. and Bourne, D.W. (eds.). MIT Press, Cambridge, Massachussetts. 256-267.

Davis, R.A., Thomson, D.H., and Malme, C.I. 1998. Environmental assessment of seismic exploration on the Scotian Shelf. Report prepared for Submission to the Canada/Nova Scotia Offshore Petroleum Board (Report prepared by LGL Ltd. and C.L. Malme for Mobil Oil Canada Properties Ltd., Shell Canada Ltd. and Imperial Oil Ltd., Calgary, Alberta). 181 pp + Appendices.

Dawe, E.G. and Beck, C.P. 1985. Distribution and size of short-finned squid (*Illex illecebrosus*) larvae in the Northwest Atlantic from winter surveys in 1969, 1981 and 1982. Journal of Northwest Atlantic Fishery Science. 6:43-55.

Dawe, E.G. and Hendriskson, L.C. 1998. A review of the biology, population dynamics, qnd exploitation of short-finned squid in the northwest Atlantic Ocean in relation to assessment and management of the resource. Northwest Atlantic Fisheries Organization (NAFO) Science Council Research Document. 98/59.

DeBlois. E.M., Leeder, C.K., Penny, C., Murdoch, M., Paine, M.D., Power, F., and Williams, U.P. 2005. Terra Nova environmental effects monitoring program: from environmental impact statement onward. IN Offshore Oil and Gas Environmental Effects Monitoring: Approaches and Tecnhologies. Armsworthy, S.L., Cranford, P.J., and Lee K. (eds.). Battelle Press, Columbus, Ohio. 475-491

DeBlois, M., Dunbar, D.S., Hollett, C., Taylor, D.G., and Wight, F.M. 2011. Produced water monitoring: use of rhodamine dye to track produced water plumes on the Grand Banks. IN Produced Water Discharge from Offshore Oil and Gas Facilities: Environmental Risks and Advances in Mitigation Technologies. Lee, K., and Neff, J. (eds.). Springer Publishing Company, New York. 472pp.

Delvigne, G.A.L. and Sweeney, C.E. 1988. Natural dispersion of oil. Oil and Chemical Pollution. 4:281-310.

Derby, J.G.S and Capuzzo, J.M. 1984. Lethal and sublethal toxicity of drilling fluids to larvae of the American lobster *(Homarus americanus)*. Canadian Journal of Fisheries and Aquatic Sciences. 41:1334-1340.

Desharnais, F. and Collison, N.E.B. 2001. An assessment of the noise field near the Sable Gully area. Oceans, 1002 MTS/IEEE Conference and Exhibition. 2: 1348-1355.

DFO (Fisheries and Oceans Canada). 1996a. Scotian Shelf Sand Lance. DFO Sci. Stock Stat. Rep. 1996/77E. 2pp.

DFO (Fisheries and Oceans Canada). 1996b. Blue Shark. DFO Atl. Fish. Res. Doc. 96/34E. 3pp.

DFO (Fisheries and Oceans Canada). 1996c. Commercial Fisheries Licensing Policy for Eastern Canada – 1996. Website <http://www.dfo-mpo.gc.ca/communic/lic_pol/index_e.htm> (cited November 26, 2009).

DFO (Fisheries and Oceans Canada). 1998. Scotian Shelf Red Crab. DFO Sci. Stock Stat. Rep. C3-11. 6pp.

DFO (Fisheries and Oceans Canada). 2000. Status of Redfish Stocks in the Northwest Atlantic: Redfish in Units 1, 2 and in Division 3O. DFO Sci. Stock Stat. Rep. A1-01. 21pp.

DFO (Fisheries and Oceans Canada). 2002a. Monkfish on the Scotian Shelf and the Northeast Georges Bank (Div. 4VWX and 5Zc). DFO Sci. Stock Stat. Rep. A3-30. 7pp.

DFO (Fisheries and Oceans Canada). 2002b. Updates on selected Scotian Shelf groundfish stocks in 2002. DFO Sci. Stock Stat. Rep. A3-35. 30pp.

DFO (Fisheries and Oceans Canada). 2002c. Wolffish on the Scotian Shelf and in the Bay of Fundy (Div 4VWX and Div. 5YZe). DFO Sci. Stock Stat. Rep. 7pp.

DFO (Fisheries and Oceans Canada). 2002d. Canadian Atlantic Pelagic Shark Integrated Fisheries Management Plan (2002-2007). DFO Integrated Fisheries Management Plan. Website < http://www.dfo-mpo.gc.ca/communic/fish_man/ifmp/shark-requin/index_e.htm> (cited 26 November 2010)>

DFO (Fisheries and Oceans Canada). 2002e. Canada's Ocean Strategy Our Oceans, Our Future: Canada's Ocean Strategy. Fisheries and Oceans Directorate: Ottawa, Ontario. 39pp.

DFO (Fisheries and Oceans Canada). 2002f. Canada's Ocean Strategy Our Oceans, Our Future: Policy and Operational Framework for Integrated Management of Estuarine, Coastal and Marine Environments in Canada. Fisheries and Oceans Directorate: Ottawa, Ontario. 43pp.

DFO (Fisheries and Oceans Canada). 2003a. A Framework to Assist DFO Consideration of Requests for Review of Seismic Testing Proposals. DFO Can. Sci. Advis. Sec. Hab. Stat. Rep. 2003/001. 12pp.

DFO (Fisheries and Oceans Canada). 2003b. State of the Eastern Scotian Shelf Ecosystem. DFO Can. Sci. Advis. Sec. Eco. Stat. Rep. 2003/004. 25pp.

DFO (Fisheries and Oceans Canada) 2004a. Atlantic Mackerel of the Northwest Atlantic in 2003. DFO Can. Sci. Advis. Sec. Stock Status Rep. 2004/018. 12pp.

DFO (Fisheries and Oceans Canada). 2004b. Biology, fishery and stock status of shortfin mako sharks (*Isurus oxyrinchus*) in Atlantic Candian waters. DFO Can. Sci. Advis. Sec. Res. Doc 2004/094. 33pp.

DFO (Fisheries and Oceans Canada). 2004c. Potential Impacts of Seismic Energy on Snow Crab. DFO Can. Sci. Advis. Sec. Hab. Stat. Rep. 2004/003. 5pp.

DFO (Fisheries and Oceans Canada). 2005a. Stock Assessment Report in NAFO Subareas 3-6 Porbeagle Shark. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2005/044. 11pp.

DFO (Fisheries and Oceans Canada). 2005b. The Scotian Shelf: an Atlas of Human Activities. Breeze, H. and Horsman, T. (eds.), Oceans and Coastal Management Division, Maritimes Region. 113pp.

DFO (Fisheries and Oceans Canada). 2006a. 2005 State of the Ocean: Chemical and Biological Oceanographic Conditions in the Gulf of Maine – Bay of Fundy, Scotian Shelf, and the Southern Gulf of St. Lawrence. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep.2006/048. 18pp.

DFO (Fisheries and Oceans Canada). 2006b. Assessment of the Recovery Poential of Shortfin Mako Sharks in Atlantic Canada. DFO Can. Sci. Advis. Sec. Res. Doc. 2006/091. 24pp.

DFO (Fisheries and Oceans Canada). 2006c. Recovery Potential Assessment Report of Shortfin Mako Sharks in Atlantic Canada. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2006/051. 9pp.

DFO (Fisheries and Oceans Canada). 2006d. Recovery potential assessment report on white sharks in Atlantic Canada. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2006/052. 6pp.

DFO (Fisheries and Oceans Canada). 2007a. Assessment of Spiny Dogfish in Atlantic Canada. DFO. Can. Sci. Advis. Sec. Sci. Advis. Rep. 2007/046. 23pp.

DFO (Fisheries and Oceans Canada). 2007b. Stock Structure, life history, fishery and abundance indices for spiny dogfish (Squalus acanthias) in Atlantic Canada. DFO Can. Sci. Advis. Sec. Res. Doc. 2007/089. 136pp.

DFO (Fisheries and Oceans Canada). 2007c. Statement of Canadian Practice with Respect to the Mitigation of Seismic Sound in the Marine Environment: Background Paper. Fisheries and Oceans Canada. Website <www.dfo-mpo.gc.ca/oceans-habitat/oceans/im-gi/seismic-sismique/information_e.asp> (cited 15 October 2010). 9pp.

DFO (Fisheries and Oceans Canada). 2008a. Assessment of Georges Bank Scallops (*Placopecten magellanicus*). DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2008/045. 12pp.

DFO (Fisheries and Oceans Canada). 2008b. Assessment of the Atlantic mackerel stock for the Northwest Atlantic (Subareas 3 and 4) in 2007. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2008/041. 15pp.

DFO (Fisheries and Oceans Canada). 2008c. Recovery Potential Assessment for Cusk (*Brosme brosme*). DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2008/024. 11pp.

DFO (Fisheries and Oceans Canada). 2008d. Status of basking Sharks in Atlantic Canada. DFO Can. Sci. Advis. Sec. Res. Doc 2008/004. 67pp.

DFO (Fisheries and Oceans Canada). 2008e. Stock assessment of Northewest Atlantic grey seals (Halichoerus grypus). DFO. Can. Sci. Advis. Sec. Sci. Advis. Rep. 2007/056. 10pp.

DFO (Fisheries and Oceans Canada). 2009a. 2008 State of the Ocean: Chemical and Biological Oceanographic Conditions in the Gulf of Maine - Bay of Fundy and on the Scotian Shelf. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2009/054. 18pp.

DFO (Fisheries and Oceans Canada). 2009b. Assessment of Jonah Crab in Lobster Fishing Area 41 (4X + 5Zc). DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2009/034. 11pp.

DFO (Fisheries and Oceans Canada). 2009c. Pollock in Div. 4VWX+5. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2009/025. 13pp.

DFO (Fisheries and Oceans Canada). 2009d. DFO. 2009. Assessment of Atlantic Halibut on the Scotian Shelf and Southern Grand Banks (NAFO divisions 3NOPs4VWX5Zc). DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2009/036. 12pp.

DFO (Fisheries and Oceans Canada). 2010. An Outline of the DFO Maritimes Region Framework for an Ecosystem Approach to Management. Fisheries and Oceans Canada, Maritimes Region: Dartmouth, Nova Scotia. 9pp.

Di Iorio, L. and Clark, C.W. 2009). Exposure to seismic survey alters blue whale acoustic communication. Biology Letters. 6:51-54.

DiBacco, C., Robert, G., and Grant, J. 1995. Reproductive cycle of the sea scallop, *Placopecten magellanicus* (Gmelin, 1791), on northeastern Georges Bank. Journal of Shellfish Research. 14:59-69.

Dickinson, J.J. and Wigley, R.L. 1981. Distribution of gammaridean Amphipoda (Crustacea) on Georges Bank. National Oceanic and Atmospheric Administration Tech. Rep., National Mar. Fish. Serv. Spec. Sci. Rep. Fish. 746.

DOE (U.S. Deptartment of Energy). 1997. Radionuclides, metals, and hydrocarbons in oil and gas operational discharges and environmental samples associated with offshore production facilities on the Texas/Louisiana continental shelf with an environmental assessment of metals and hydrocarbons. Report to U.S. Dept. of Energy, Bartlesville, Oklahoma (Prepared by Continental Shelf Associates, Jupiter, Florida).

DOI (U.S. Department of Interior). 1977. Baseline monitoring studies, Mississippi, Alabama, Florida, Outer Continental Shelf, 1975-1976. Volume VI. Rig Monitoring. Assessment of the Environmental Impact of Exploratory Drilling. Prepared by the State University System of Florida, Institute of Oceanography. Contract 08550-CT5-30, Bureau of land Management, Washington, D.C.

Doneker, R.L. and Jirka, G.H. 2007. CORMIX User Manual: A Hydrodynamic Mixing Zone Model and Decision Support System for Pollutant Discharges into Surface Waters. U.S. EPA-823-K-07-001.

Drinkwater, K.F. and Loder, J.W. 2001. Near-surface horizontal convergence and dispersion near the tidal-mixing front on northeastern Georges Bank. Deep-Sea Research II. 48:311-339.

Drinkwater, K.F., Mountain, D.B., and Herman, A. 1998. Recent changes in the hydrography of the Scotian Shelf and Gulf of Maine – A return to conditions of the 1960s?. NAFO SCR Doc. No. 37, Serial No. N3024.

Drozdowski, A., Hannah, C., and Tedford., T. 2004. BBLT Version 7.0 user's manual. Can. Tech. Rep. Hydrogr. Ocean Sci. 240. vi + 69pp.

Duinker, P.N. 1989. Ecological effects monitoring in environmental impact assessment: what can it accomplish? Environmental Management. 13:797–805.

Durbin, E.G. and Casas, M.C. 2006. Abundance and spatial distribution of copepods on Georges Bank during the winter/spring period. Deep-Sea Research II. 53:2537-2569.

Durbin, E. G., Campbell, R. G., Casas, M.C., Ohman, M.D., Niehoff, B., Runge, J.A., and Wagner, M. 2003. Interannual variation in phytoplankton blooms and zooplankton productivity and abundance in the Gulf of Maine during winter. Marine Ecology Progress Series. 254:81-100.

Durell, G., Johnsen, S., Røe Utvik, T., Frost, T., and Neff, J. 2006. Oil well produced water discharges to the North Sea. Part I: Comparison of deployed mussels (*Mytilus edulis*), semi- permeable membrane devices, and the DREAM Model predictions to estimate the dispersion of polycyclic aromatic hydrocarbons. Marine Environmental Research. 62:194-223.

Dutta, T.K. and Harayama, S. 2000. Fate of crude oil by the combination of photooxidation and biodegradation. Environmental Science and Technology. 34:1500-1505.

Eckert, S.A., Bowles, A., and Berg, E. 1998. The effect of seismic airgun surveys on leatherback sea turtles (Dermochelys coriacea) during the nesting season. A report submitted to BHP Petroleum, Sandiego, California (Report prepared by the Hubbs-Sea World Research Institute).

Edds-Walton, P. L. and Finneran, J.J. 2006. Evaluation of evidence for altered behavior and auditory deficits in fishes due to human-generated noise sources. SSC Tech. Rep. SSC. San Diego, California. 54pp.

Edwards, R.L. 1968. Fishery resources of the North Atlantic area. IN The Future of the Fishing Industry of the United States, Volume 4. Gilbert, D.W. (ed.). University of Washington Publications in Fisheries, Seattle, Washington. 52-60.

Elner, R.W. and Campbell, A. 1987. Natural diets of lobster Homarus americanus from barren ground and macroalgal habitats off southwestern Nova Scotia, Canada. Marine Ecology Progress Series 37:131-140.

Engås, A., Løkkeborg, S., Ona, E., and Soldal, A.V. 1996. Effects of seismic shooting on local abundance and catch rates of cod (*Gadus morhua*) and haddock (*Melanogrammus aeglefinus*). Canadian Journal of Fisheries and Aquatic Sciences. 53:2238–2249.

Environment Canada. 2009. Atlantic Regional Environmental Emergencies Team. Website <http://www.ns.ec.gc.ca/emergencies/reet.html> (cited November 23, 2009).

Etnoyer, P. and Morgan, L. 2003. Occurrences of habitat-forming deep sea corals in the Northeast Pacific Ocean. . Technical Report, NOAA Office of Habitat Conservation, Marine Biology Conservation Institute. 31pp.

Evans, S.M. 1986. Control of marine pollution generated by offshore oil and gas exploration and exploitation: the Scotian Shelf. Marine Policy. 10:258–70.

Exxon Norge AS. 2001 Coexisting with the Fishing Industry. Website <www.exxonmobil.com/Files/PA/Norden/Coexisting_with_Fishing_Industry.pdf> (cited 14 October 2010). 19pp.

Fang, Q., Guo, B., and Ghalambor, A. 2008. Formation of underwater cuttings piles in offshore drilling. SPE Drilling & Completion. 23:23-28.

FAO (Food and Agriculture Organization of the United Nations). 2005. Guidelines for the Ecolabelling of Fish and Fishery Products from Marine Capture Fisheries. Rome. Website <http://www.fao.org/docrep/008/a0116t/a0116t01.htm> (cited January 15, 2010). 98pp.

Fingas, M.F. 1995. A literature review of the physics and predictive modelling of oil spill evaporation. Journal of Hazardous Materials. 42:157-175.

Fingas, M.F. Li K., Ackerman F., Bissonnette, M.C., Lambert, P., Nelson, R., Halley, G., Campagna, P.R., Laroche, N., Jokuty, P., Turpin, R.D., Trespalacios, M.J., Belanger, J., Vanderkooy, N., Tennyson, E.J., Aurand, D., and Hiltrabrand, R. 1994. The Newfoundland offshore burn experiment: NOBE. IN Proceedings of the 1994 International Oil Spill Conference. American Petroleum Institute, Washington, D.C.123-132.

Fingas, M.F., Wang, Z, Fieldhouse B., Brown, C.E., Yang, C. and Landriault M. 2005. In-Situ burning of heavy oils and orimulsion: Analysis of soot and residue. Proceedings of the 28th Arctic and Marine Oilspill Program (AMOP) Technical Seminar. Environment Canada, Ottawa, Ontario. 333-348.

Finstad, J.L. and Nordeide, J.T. 2004. Acoustic repertoire of spawning cod, *Gadus morhua*. Environmental Biology of Fishes. 40:427-433.

Fiocco, R.J., DeMarco, G., Lessard, R.R., Daling, P.S., and Canevari, G.P. 1999. Chemical dispersibility study of heavy bunker fuel oil. IN Proceedings of the 22nd Arctic and Marine Oilspill Program (AMOP) Technical Seminar. Environment Canada, Ottawa, Ontario. 173-186.

Fish, M.P. and Mowbray, W.H. 1970. Sounds of Western North Atlantic Fishes. John Hopkins Press, Baltimore. 231pp.

Fisher, J.B. 1987. Distribution and occurrence of aliphatic acid anions in deep subsurface waters. Geochimica et Cosmochimica Acta. 51:2459-2468.

Flagg, C.N. 1987. Hydrographic structure and variability. IN Georges Bank. Backus, R.H. and Bourne, D.W. (eds.). MIT Press, Cambridge, Massachusetts. 108-124.

Flagg, C.N., Magnell, B.A., Frye, D., Cura, J.J., McDowell, S.E., and Scarlet, R.I. 1982. Interpretation of the physical oceanography of Georges Bank. Report prepared for U.S. Dept. of Interior, Bureau of Land Management (Report prepared by EG&G Environmental Consultants, Waltham, Massachussetts).

Forbes, V.E., Palmqvist A., and Bach, L. 2006. The use and misuse of biomarkers in ecotoxicology. Environmental Toxicology and Chemistry. 25:272-280.

Førlin, L. and Hylland, K. 2006. Hepatic cytochrome P4501A concentration and activity in Atlantic cod caged in two North Sea pollution gradients. IN Biological Effects of Contaminants in Marine Pelagic Ecosystems. Hylland, K., Lang, T., and Vethaak, D. (eds.). SETAC Press, Pensacola, Florida. 253-261.

Forsyth, J.V., Tsao, Y.M., and Blem, R.D. 1995. Bioremediation: when is augmentation needed? IN Bioaugmentation for Site Remediation. Hinchee, R.E., Fredrickson, J., and Alleman, B. C. (eds). Battelle Press, Columbus, Ohio. 1-14.

Forteath, G.N.R, Picken, G.B., Ralph R., and Williams J. 1982. Marine growth studies on the North Sea oil platform Montrose Alpha. Marine Ecology Progress Series 8:61-68.

Fosså, J.H., Mortensen, P. and Furevik, D. 2002. The deep-water coral *Lophelia pertusa* in Norwegian waters: distribution and fishery impacts. Hydrobiologia. 471:1-12.

Fowler, S.L., Cavanagh, R.D., Camhi, M., Burgess, G.H., Cailliet, G.M., Fordham, S.V., Simpfendorfer, C.A., and Musick, J.A.. 2005. Sharks, Rays and Chimaeras: The Status of the Chondrichthyan Fishes. Status Survey. IUCN/SSC Shark Specialist Group. IUCN, Gland, Switzerland and Cambridge, United Kingdom.

Frank, K.T., Petrie, B., Shackell, N.L., Choi, J.S. 2006. Reconciling differences in trophic control in mid-latitude marine ecosystems. Ecological Letters. 9:1096-1105.

Franks, P.J.S. and Chen, C. 2001. A three-dimensional prognostic model study of the ecosystem over Georges Bank and adjacent coastal regions, Part II: coupled biological and physical model. Deep Sea Research II. 48:457-482.

Fraser, G.S. and Ellis, J. 2008. Offshore hydrocarbon and synthetic hydrocarbon spills in eastern Canada: The issue of follow-up and experience. Journal of Environmental Assessment Policy and Management. 10:173-187.

Fraser, T.P. and Wicks, M. 1995. Estimation of maximum stable oil droplet sizes at sea resulting from natural dispersion and from use of a dispersant. IN Proceedings of the 18 th Arctic and Marine Oilspill Program (AMOP) Technical Seminar. Environment Canada, Ottawa, Ontario. 313-316.

French-McCay. D. 2003. Development and application of damage assessment modeling: example assessment for the North Cape oil spill. Marine Pollution Bulletin. 47:341-359.

French-McCay, D. 2004a. Oil spill impact modeling: development and validation. Environmental Toxicology and Chemistry. 23:2441-2456.

French-McCay, D. 2004b. Evaluation of bird impacts in historical oil spill cases using the SIMAP oil spill model. IN Proceedings of the 27th Arctic and Marine Oilspill Program (AMOP) Technical Seminar. Environment Canada, Ottawa, Ontario. 421-452.

French-McCay, D.P. and Payne, J.R. 2001. Model of oil fate and water concentrations with and without application of dispersant. IN Proceedings of the 24th Arctic and Marine Oilspill Program (AMOP) Technical Seminar. Environment Canada, Ottawa, Ontario.

French-McCay, D., Whittier, N., Sankaranarayanan, S., Jennings, J., and Etkin, D.S. 2002. Modeling fates and impacts for bio-economic analysis of hypothetical oil spill scenarios in San Francisco Bay. IN Proceedings of the 25th Arctic and Marine Oilspill Program (AMOP) Technical Seminar. Environment Canada, Ottawa, Ontario.1051-1074.

French-McCay, D., Whittier, N., Isaji, T., and Saunders, W. 2003. Assessment of potential impacts of oil spills in the James River, Virginia. IN Proceedings of the 26th Arctic and Marine Oilspill Program (AMOP) Technical Seminar. Environment Canada, Ottawa, Ontario. 857-877.

Friedland, K. and Hare, J. 2007. Long-term trends and regime shifts in sea surface temperature on the Continental Shelf of the northeast United States. Continental Shelf Research. 27:2313-2328.

Fudge, S.B. and Rose, G.A. 2009. Passive- and active-acoustic properties of a spawning Atlantic cod (*Gadus morhua*) aggregation. ICES Journal of Marine Science. 66:1259-1263.

Fujiwara, M. and Caswell, H. 2001. Demography of the endangered North Atlantic right whale. Nature. 414:537-541.

Gaichas, S., Skaret, G., Falk-Petersen, J., Link, J., Overholtz, W., Megrey, B., Gjoesaeter, H., Stockhausen, W., Dommasnes, A., Friedland, K., and Aydin, K. 2009. A comparison of community and trophic structure in five marine ecosystems based on energy budgets and system metrics. Progress in Oceanography. 81:47-62.

Gallaway, B.J., Martin, L.R., Howard, R.L., Boland, G.S., and Dennis, G.D. 1981. Effects on artificial reef and demersal fish and macrocrustacean communities. IN Environmental Effects of Offshore Oil Production: The Buccaneer Gas and Oilfield Study. Middleditch, B.S. (ed.). Marine Science. Plenum, New York. 14:237-299.

Gamble, J.C., Davies, J.M., Hay, S.J., and Dow, F.K. 1987. Mesocosm experiments on the effects of produced water discharges from offshore oil platforms in the northern North Sea. Sarsia. 72:383-386.

Gardner Pinfold Consulting Economists Limited. 1988. Georges Bank Resources: An Economic Profile. Prepared for Georges Bank Panel Review, Halifax, Nova Scotia, Canada. 68pp.

Garland, E. 2005. Environmental regulatory framework in Europe: an update. Presented at the 2005 SPE/EPA/DOE Exploration and Production Environmental Conference, March 7-9, 2005, Galveston, Texas. Society of Petroleum Engineers, Inc. 10pp.

Garrett, C.J.R. 1972. Tidal resonance in the Bay of Fundy and Gulf of Maine. Nature. 238:441-443.

Garrett, C.J.R., Keeley, J.R., and Greenberg, D.A. 1978. Tidal mixing versus thermal stratification in the Bay of Fundy and Gulf of Maine. Atmosphere-Ocean. 16:403-423.

Garrett, R.M., Pickering, I.J., Haith, C.E., and Prince, R.C. 1998. Photooxidation of crude oils. Environmental Science and Technology. 32:3719-3723.

Garrison, L.P. and Link, J.S. 2000a. Dietry guild structure of the fish community in the Northeast United States continental shelf ecosystem. Marine Ecology Progress Series. 202:231-240.

Garrison, L.P. and Link, J.S. 2000b. Fishing effects on spatial distribution and trophic guild structure of the fish community in the Georges Bank region. ICES Journal of Marine Science. 57:723-730.

Gaston, A.J. and Hipfner, J.M. 2000. Thick-billed Murre (*Uria lomvia*). IN The Birds of North America, No. 497. Poole, A. and Gill, F. (eds.). The Birds of North America, Inc., Philadelphia, Pennsylvania.

Gavaris, S., O'Boyle, R., and Overholtz, W. 2005. Proceedings of the Transboundary Resources Assessment Committee (TRAC) benchmark review of stock assessment models for the Georges Bank yellowtail flounder stock. TRAC Proceedings 2005/01. 40pp.

Gedamke, T., DuPaul, W.D., and Musick, J.A. 2005. Observations on the life history of the barndoor skate, *Dipturus laevis*, on Georges Bank (Western North Atlantic). Journal of Northwest Atlantic Fishery Science. 35:67-78.

George, D.A. and Hill, P.S. 2008. Wave climate, sediment supply and the depth of the sand-mud transition: A global survey. Marine Geology. 254:121-128.

George, S.G., Wright, J., and Conroy, J. 1995. Temporal studies of the impact of the Braer oil spill on inshore feral fish from Shetland, Scotland. Archives of Environmental Contamination and Toxicology. 29:530-534.

GESAMP (IMO/FAO/UNSERCO/WMO/WHO/IAEA/UN/UNEP Joint Group of Experts on the Scientific Aspects of Marine Pollution). 1991. Global Strategies for Marine Environmental Protection. GESAMP Reports and Studies No. 45. 34pp.

GESAMP (IMO/FAO/UNSERCO/WMO/WHO/IAEA/UN/UNEP Joint Group of Experts on the Scientific Aspects of Marine Pollution). 1993. Impact of oil and related chemicals and wastes on the marine environment. GESAMP Reports and Studies No. 50. 180pp.

GESAMP (IMO/FAO/UNSERCO/WMO/WHO/IAEA/UN/UNEP Joint Group of Experts on the Scientific Aspects of Marine Pollution). 1995. Biological indicators and their use in the measurements of the condition of the marine environment. GESAMP Reports and Studies No. 55. 56pp.

GESAMP (IMO/FAO/UNESCO-IOC/UNIDO/WMO/IAEA/UN/UNEP Joint Group of Experts on the Scientific Aspects of Marine Environmental Protection). 2007. Estimates of oil entering the marine environment from sea-based activities. GESAMP Reports and Studies No. 75. 96pp.

Getliff, J.M. and James, S.G. 1996. The replacement of alkyl-phenol ethoxylates to improve environmental acceptability of drilling fluid additives. IN Proceedings of the SPE Health, Safety and Environment in Oil and Gas Exploration and Production Conference, June 9-12, 1996, New Orleans, Louisiana. Society of Petroleum Engineers, Inc. 7pp.

Gilbert, C.S., Gentleman, W.C., Johnson, C.L., DiBacco, C., Pringle, J.M., and Chen, C.S. 2010. Modeling transport of Sea Scallop (*Placopecten magellanicus*) larvae on Georges Bank: Influence of behavior and spawning seasonality. Progress in Oceanography. 87:37-48.

Golet, W.J. 2010. Somatic Condition, Growth and Distribution of Atlantic Bluefin Tuna (Thunnus thynnus) in the Gulf of Maine. Doctoral Dissertation, University of New Hampshire, New Hampshire.

GOMA (Gulf of Maine Area: Census of Marine Life). 2010. Georges Bank and Great South Channel. Website <www.gulfofmaine-census.org/about-the-gulf/physical-characteristics/physioregions> (cited November 1, 2010).

Good, T.P. 1998. Great black-backed gull (*Larus marinus*). IN The Birds of North America, No. 330. Poole, A. and Gill, F. (eds.). The Birds of North America, Inc., Philadelphia, Pennsylvania.

Gordon, D.C.Jr. 1988. An assessment of the possible environmental impacts of exploratory drilling on Georges Bank fishery resources. Can. Tech. Rep. Fish. Aquat. Sci. 1633. 31pp.

Gordon, D., and Kenchington, E. 2007. Deep-water corals in Atlantic Canada: a review of DFO research (2001-2003). Proceedings of the Nova Scotian Institute of Science. 44:27-50.

Gordon, D.C.Jr., Cranford, P.J., Hannah, C.G., Loder, J.W. Milligan, T.G., and Muschenheim, D.K. 2000. The potential effects of exploratory hydrocarbon drilling on Georges Bank scallop populations. Can. Tech. Rep. Fish. Aquat. Sci. 2317. 16 pp.

Gosselin, J.F. and Lawson, J.W. 2005. Distribution and abundance indicies of marine mammals in the Gully and two adjacent canyons of the Scotian Shelf before and during nearby hydrocarbon seismic exploration programs in April and July 2003. IN Acoustic Monitoring and Marine Mammal Surveys in the Gully and Outer Scotian Shelf Before and During Active Seismic Programs. Environmental Studies Research Funds Report No.151. Lee, K., Bain, H., and Hurley, G.V. (eds). Environmental Studies Research Funds, Calgary, Alberta. 117-138.

Government of Canada. 2003. A Framework for the application of precaution in science-based decision making about risk. Privy Council Office Publication No. CP22-70/2003 (ISBN 0-662-67486-3), Ottawa, Ontario. Website <www.pco-bcp.gc.ca/docs/information/publications/precaution/precaution-eng.pdf> (cited 27 October 2010). 15pp.

Government of Canada. 2004. Strategic Environmental Assessment – The Cabinet Directive on the Environmental Assessment of Policy, Plan and Program Proposals. Published jointly by the Privy Council Office and the Canadian Environmental Assessment Agency, Ottawa, Canada, Catalogue No. EN21-190/2004. 10pp.

Government of Canada. 2007. Statement of Canadian Practice with Respect to the Mitigation of Seismic Sound in the Marine Environment. Fisheries and Oceans Canada, Ottawa, Ontario. Website <www.dfo-mpo.gc.ca/oceans/management-gestion/integratedmanagementgestiointegree/seismic-sismique/statement-enonce-eng.asp> (cited 15 October , 2010). 5pp.

Government of Canada. 2011. Aboriginal Consultation and Accommodation: Updated Guidelines for Federal Officials to Fulfill the Duty to Consult. Catalogue No. R3-111/2011E-PDF, Ottawa, Ontario. 68pp.

Grant, A.C., Levy, E.M., Lee, K., and Moffatt, J.D. 1986. PISCES IV research submersible finds oil on Baffin shelf. Current Research, Part A, Geological Survey of Canada. 86-1A: 65-69.

Grant, W.D. and Madsen, O.S. 1986. The continental shelf bottom boundary layer. Annual Review of Fluid Mechanics. 18:265-305.

Gray, J.S. 2002. Perceived and real risks: produced water from oil extraction. Marine Pollution Bulletin. 44:1171-1172.

Greene, C.R.J. and Moore, S.E. 1995. Man-made noise. IN Marine Mammals and Noise. D.H. Thomson (ed.). Academic Press, San Diego, Califorinia. 101-158.

Greene, C.H. and Pershing, A.J. 2007. Climate drives sea change. Science. 315:1084-1085.

Grizzle, J.M. 1986. Lesions in fishes captured near drilling platforms in the Gulf of Mexico. Marine Environmental Research. 18:267-276.

Guénette, C.C., Sveum, P., Bech, C.M., and Buist, I.A. 1995. Studies of in-situ burning of emulsions in Norway. Proceedings of the 1995 International Oil Spill Conference. American Petroleum Institute, Washington D.C. 8110-8125.

Guerra, A., Gonzalez, A.F., and Rocha, F. 2004. A review of the records of giant squid in the north-eastern Atlantic and severe injuries in *Architeuthis dux* stranded after acoustic explorations. ICES Annual Science Conference, September 22 -25, 2005, Vigo, Spain. ICES CM 2004 / CC:29. 1-17.

Haapkylä, J., Ramade, F., Salvato B. 2007. Oil pollution on coral reefs: A review of the state of knowledge and management needs. Life and Environment 57: 91-107.

Hahm, W. and Langton, R. 1984. Prey selection based on predator/prey weight ratios for some northwest Atlantic fish. Marine Ecology Progress Series. 19:1-5.

Hammill, M.O. and Stenson, G.B. 2000. Estimated pey consumption by harp seals (*Phoca groenlandica*), hooded seals (*Cystophora cristata*), grey seals (*Halichoerus grypus*) and harbour seals (*Phoca vitulina*) in Atlantic Canada. Journal of Northwest Atlantic Fishery Science. 26:1-23.

Hamoutene D., Payne, J.F., Andrews, C., and Guiney, J. 2004. Effect of a synthetic drilling fluid (IPAR) on antioxidant enzymes and peroxisome proliferation in the American lobster, *Homarus americanus*. Can. Tech. Rep. Fish. Aquat. Sci. 2554. iii + 12pp.

Hamoutene. D., Volkoff, H., Parrish, C., Samuelson, S., Mabrouk, G., Mansour, A., Mathieu, A., King, T., and Lee, K. 2011. Effect of produced water on innate immunity, feeding and antioxidant metabolism in Atlantic cod (*Gadus morhua*). IN Produced Water Discharge from Offshore Oil and Gas Facilities: Environmental Risks and Advances in Mitigation Technologies. Lee, K., and Neff, J. (eds.). Springer Publishing Company, New York. 492pp.

Hanke, A.R., Page, F.H., and Neilson, J. 2001. Distribution of pollock (*Pollachius virens*) eggs and larvae on the Scotian Shelf, eastern Gulf of Maine, Bay of Fundy and eastern Georges Bank. Can. Tech. Fish. Aqua. Sci. 2345. 118pp.

Hannah, C.G., Shen, Y., Loder, J.W., and Muschenheim, D.K. 1995. BBLT: Formulation and exploratory applications of a benthic boundary layer transport model. Can. Tech. Rep. Hydrogr. Ocean Sci. 166. vi + 52pp.

Hannah, C.G., Loder, J.W., and Shen, Y. 1996. Shear dispersion in the benthic boundary layer. IN Estuarine and Coastal Modeling: Proceedings of the 4th International Conference. Spaulding, M.L. and Cheng, R.T. (eds.). ASCE, New York. 454-465.

Hannah, C.G., Naimie, C.E., Loder, J.W., and Werner, F.E. 1998. Upper-ocean transport mechanisms from the Gulf of Maine to Georges Bank, with implications for Calanus supply. Continental Shelf Research. 17:1887-1911.

Hannah, C.G., Drozdowski, A., Muschenheim, D.K., Loder, J., Belford, S., and MacNeil, M. 2003. Evaluation of drilling mud dispersion models at SOEI Tier I sites: Part 1 North Triumph, Fall 1999. Can. Tech. Rep. Hydrogr. Ocean Sci. 232. v + 51 pp.

Hannah, C.G. and Drozdowski, A. 2005. Characterizing the near-bottom dispersion of drilling mud on three Canadian offshore banks. Marine Pollution Bulletin. 50:1433-1456.

Hannah, C.G., Drozdowski, A., Loder, J., Muschenheim, K., and Milligan, T. 2006. An assessment model for the fate and environmental effects of offshore drilling mud discharges. Estuarine, Coastal and Shelf Science. 70:577-588.

Harding, G.C., Pringle, J.D., Vass, W.P., Pearre, S.Jr., and Smith, S.J. 1987. Vertical distribution and daily movements of larval lobsters *Homarus americanus* over Browns Bank, Nova Scotia. Marine Ecology Progress Series. 41:29-41.

Harding, G.C., Drinkwater, K.F., Pringle, J.D., Fraser, A.J., Prena, J., Pearre, S.Jr., Perry, R.I.Jr., and Vass W.P. 1995. Studies on the effect of the frontal zone on the northern face of Georges Bank, Gulf of Maine, on larval lobster and plankton distribution. ICES, Copenhagen (Denmark). ICES-CM-1990/L:8.

Harding, G.C., Drinkwater, K.F., Hannah, C.G., Pringle, J.D., Prena, J., Loder, J.W., Pearre, S.Jr., and Vass. W.P. 2005. Larval lobster (*Homarus americanus*) distribution and drift in the vicinity of the Gulf of Maine offshore banks and their probable origins. Fisheries Oceanography. 14:112-137.

Hareide, N.R. and Garnes, G. 2001. The distribution and catch rates of deep water fish along the Mid-Atlantic Ridge from 43 to 61 degrees N. Fisheries Research. 51:297-310.

Harris, G. 1998. Toxicity test results of five drilling muds and three base oils using benthic amphipod survival, bivalve survival, echinoid fertilization and Microtox. Report for Sable Offshore Energy Inc. (Report prepared by Harris Industrial Testing Services Ltd). 11pp.

Harris, L.E. and Hanke, A.R. 2010. Assessment of the Status, Threats and Recovery Potential of Cusk (*Brosme brosme*). DFO Can. Sci. Adv. Sec. Res. Doc. 2010/004. 29pp.

Harris, L.E., Comeau, P.A., and Clark, D.S. 2002. Evaluation of Cusk (*Brosme brosme*) in Canadian Waters. DFO Can. Sci. Advis. Sec. Res. Doc. 2002/104. 40pp.

Harrison, P. 1988. Seabirds: An identification guide. Houghton Mifflin Harcourt, London. 448pp.

Harrison, G., Johnson, C., Head, E., Spry, J., Pauley, K., Maass, H., Kennedy, M., Porter, C., and Soukhovtsev, V. 2009. Optical, chemical and biological oceanographic conditions in the Maritimes region in 2008. DFO Can. Sci. Advis. Sec. Res. Doc. 2009/054. 61pp.

Hart, A.D., Graham, B.D., and Gettleson, D.A. 1995. NORM associated with produced water discharges. IN Proceedings of the SPE/EPA Exploration & Production Environmental Conference, Houston, Texas. Society of Petroleum Engineers, Inc. SPE 29727. 12pp.

Hassel, A., Knutsen, T., Dalen, J., Skaar, K., Løkkeborg, S., Misund, O. A., Østensen, Ø., Fonn, M., and Haugland, E. K. 2004. Influence of seismic shooting on the lesser sandeel (*Ammodytes marinus*). ICES Journal of Marine Science. 61:1165 - 1173.

Hatch, S.A. 1987. Adult survival and productivity of Northern Fulmars in Alaska. Condor. 89:685-696.

Hatch, S.A. and Nettleship, D.N. 1998. Northern fulmar (*Fulmarus glacialis*). IN The Birds of North America, No. 361. Poole, A. and Gill, F. (eds.). The Birds of North America, Inc., Philadelphia, Pennsylvania.

Hawkins, A.D. 1986. Underwater sound and fish behaviour. IN Behaviour of Teleost Fishes. Pitcher, T.J. (ed.). Croom Helm, London. 114-151.

Hawkins, A.D. and Rasmussen, K.J. 1978. The sounds of gadoid fish. Journal of the Marine Biological Association of the United Kingdom. 58:891-911.

Hawkins, A.D. and Amorim, M.C.P. 2000. Spawning sounds of the male haddock, *Melanogrammus aeglefinus*. Environmental Biology of Fishes. 59:29-41.

Hawkins, A.D., Chapman, C.J., and Symonds, D.Y. 1967. Spawning of haddock in captivity. Nature 215:923-925.

Hellawell, J.M. 1991. Development of a rationale for monitoring. IN Monitoring for Conservation and Ecology. Goldsmith, F.B. (ed.). Chapman Hall: London. 1-14.

Henderson, S.B., Grigson, S.W., Johnson, P., and Roddie, B.D. 1999. Potential impact of production chemicals on toxicity of produced water discharges in North Sea oil platforms. Marine Pollution Bulletin. 38:1141-1151

Hendrickson, L.C. 2004. Population biology of northern shortfin squid (*Illex illecebrosus*) in the Northwest Atlantic Ocean and initial documentation of a spawning area. ICES Journal of Marine Science. 61:252-266.

Hendrickson, L.C. and Holmes, E.M. 2004. Essential fish habitat source document: northernshortfin squid, Illex illecebrosus, life history and habitat characteristics, 2nd Edition. NOAA Tech. Memo. NMFS-NE-191. 46pp.

Hendrickson, L.C. and Jacobson, L. 2006. Longfin Inshore Squid *(Loligo pealeii)*. Website <http://www.nefsc.noaa.gov/sos/spsyn/iv/lfsquid> (cited 2 February 2010).

Hildebrand, J.A. 2005. Impacts of anthropogenic sound. IN Marine Mammal Research: Conservation Beyond Crisis. Reynolds, J.E., Perrin, W.F., Reeves, R.R., Montgomery, S., and Ragen, T.J. (eds). John Hopkins University Press, Baltimore, Maryland. 101-124.

Hobbie J.E., Novitsky, T.J., Rublee, P.A., Ferguson, R.L., and Palumbo, A.V. 1987. Microbiology. IN Georges Bank. Backus, R.H. and D.W. Bourne, D.W. (eds.). MIT Press, Cambridge, Massachusetts. 247-251.

Hodgins, D.O. and Hodgins, S.L.M. 1998. Distribution of well cuttings and produced water for the Terra Nova development. Report prepared for Terra Nova Alliance, St. John's, Newfoundland and Labrador (Report prepared by Seaconsult Marine Research Ltd., Vancouver, British Columbia). 40pp. + App.

Hodgins, D.O. and Hodgins, S.L.M. 2000. Modelled predictions of well cuttings deposition and produced water dispersion for the proposed White Rose development. Report prepared for Husky Oil Operations Ltd, St. John's, Newfoundland and Labrador (Report prepared by Seaconsult Marine Research Ltd., Vancouver, British Columbia).

Hodson, P.V., Khan, C.W., Saravanabhavan, G., Clarke, L., Brown, R.S., Hollebone, B., Wang, Z., Short, J., Lee, K., and King, T. 2007. Alkyl PAH in crude oil cause chronic toxicity to early life stages of fish. IN Proceedings of the 30th Arctic and Marine Oil Spill Program (AMOP) Technical Seminar. Environment Canada, Ottawa, Ontario. 291-299.

Holdway, D.A. 2002. The acute and chronic effects of wastes associated with offshore oil and gas production on temperate and tropical marine ecological processes. Marine Pollution Bulletin. 44:185-203.

Holst, M., Richardson, W.J., Koski, W.R., Smultea, M.A., Haley, B., Fitzgerald, M.W., and Rawson, M. 2006. Effects of large- and small-source seismic surveys on marine mammals and sea turtles. EOS, Transactions of the American Geophysical Union 87, Joint Assembly Supplement, May 23-26, 2006, Baltimore, Maryland. Abstract OS42A-01.

Horne, E.P.W., Loder, J.W., Harrison, W.G., Mohn, R., Lewis, M.R., Irwin, B., and Platt, T. 1989. Nitrate supply and demand at the Georges Bank tidal front. Scientia Marina. 53:145-158.

Houghton, J.P., Britch, R.P., Miller, R.C., and Runchal, A.K. 1980. Drilling fluid dispersion studies at the Lower Cook Inlet, Alaska. IN Proceedings of Symposium, Research on Environmental Fate and Effects of Drilling Fluids and Cuttings, January 21-24, 1980, Lake Buena Vista, Florida. Vol I:285-308.

Houser, D.S., Howard, R., and Ridgway, S. 2001. Can diving-induced tissue nitrogen supersaturation increase the chance of acoustically driven bubble growth in marine mammals? Journal of Theoretical Biology. 213:183-195.

Hu, S., Townsend, D.W., Chen, C., Cowles, G., Beardsley, R.C., Ji, R., and Houghton, R.W. 2008. Tidal pumping and nutrient fluxes on Georges Bank: A process-oriented modeling study. Journal of Marine Systems. 74:528-544.

Huang, J.C. 1983. A review of the state-of-the-art of oil spill fate/behaviour models. IN Proceedings of the 1983 International Oil Spill Conference. American Petroleum Institute, Washington D.C. 313-322.

Huntington, C.E., Butler, R.G., and Mauck, R.A. 1996. Leach's Storm-Petrel (*Oceanodroma leucorhoa*). IN The Birds of North America, No. 233. Poole, A. and Gill, F. (eds.). The Birds of North America, Inc., Philadelphia, Pennsylvania.

Hurley, G.V. 2000. Nearshore and offshore environmental effects monitoring at the Sable Offshore energy project. IN Understanding the Environmental Effects of Offshore Hydrocarbon Development. Gordon, D.C.Jr., Griffiths, L.D., Hurley, G.V., Muecke, A.L., Muschenheim, D.K., and Wells, P.G. (eds.). Can. Tech. Rep. Fish. Aquat. Sci. 2311. 39-42.

Hurley, G.V. 2009. Environmental assessment biophysical data gap study – petroleum exploration activities on the offshore Scotian Shelf and Slope. Report prepared for the Canada-Nova Scotia Petroleum Board, Halifax, Nova Scotia (Report prepared by Hurley Environment Ltd., Dartmouth, Nova Scotia). 122pp.

Hurley, G.V. and Ellis, J. 2004. Environmental effects of exploratory drilling offshore Canada: EEM data and literature review. Final Report Prepared for the Canadian Environmental Assessment Agency's Regulatory Advisory Committee (RAC). 61pp. + App.

Husky Energy. 2005. White Rose Environmental Effects monitoring program 2005 (Volumes 1 and 2). Website<www.huskyenergy.com/downloads/areasofoperations/eastcoast/HSE/WhiteRose2005EEMReport_Vol1.pdf> (cited 21 October 2010). 212pp.

Hylland, K., Lang,T., and Vethaak, D. 2006. Biological Effects of Contaminants in Marine Pelagic Ecosystems. SETAC Press, Pensacola, Florida. 474pp.

IAGC (International Association of Geophysical Contractors). 2002. Marine Seismic Operations: An Overview. Website:<www.iagc.org/attachments/contentmanagers/4352/Marine%20Seismic%20Operations%20Overview.pdf>(cited 27 October 2010). 21pp.

ICCAT (The International Commission for the Conservation of Atlantic Tunas). 1999. Recommendation by ICCAT to establish a rebuilding plan for Western Atlantic bluefin tuna. IN ICCAT Report for biennial period, 1998-99. Part 1:Annex 5-7.

ICCAT (The International Commission for the Conservation of Atlantic Tunas). 2000. Recommendation by ICCAT to establish a rebuilding program for North Atlantic wwordfish in report for biennial period, 1998-99. Part II:Annex 5-2.

ICCAT (The International Commission for the Conservation of Atlantic Tunas). 2005. Report of the 2004 ICCAT bigeye tuna stock assessment session. Coll. Vol. Sci. Pap. ICCAT. 58:1-110.

ICCAT (The International Commission for the Conservation of Atlantic Tunas). 2007. 2006 ICCAT workshop on swordfish stock structure. Coll. Vol. Sci. Pap. ICCAT. 61.

ICCAT (The International Commission for the Conservation of Atlantic Tunas). 2009a. Report of the 2009 Atlantic swordfish stock assessment session. ICCAT SCRS/2009/016.

ICCAT (The International Commission for the Conservation of Atlantic Tunas). 2009b. Report of the 2008 Atlantic bluefin stock assessment session. Col. Vol. Sci. Pap. ICCAT. 64.

ICCAT (The International Commission for the Conservation of Atlantic Tunas). 2009c. Report of the 2008 ICCAT yellowfin and skipjack stock assessments meeting. Coll. Vol. Sci. Pap. ICCAT. 64.

ICCAT (The International Commission for the Conservation of Atlantic Tunas). 2009d. Report for biennial period, 2008-2009. ICCAT SCRS Part I, Vol. 2.

ICCAT (The International Commission for the Conservation of Atlantic Tunas). 2009e. Report of the 2009 ICCAT albacore stock assessment session. ICCAT SCRS 2009-09.

ICES (International Council for the Exploration of the Sea). 1994. Report of the joint meeting of the working group on marine sediments in relation to pollution and the working group on biological effects of contaminants. Nantes, France. ICES C.M. 1994/ENV:2. 19 pp.

IESL (Innovative Engineering Systems Limited). 2003. SizeCUT^{TM}. Innovative Engineering Systems Limited Technical Brochure. Website <www.iesl-global.com/brochures/SizeCUT.pdf> cited (19 October 2010). 19pp.

Incze, L. 1998. Hypsometric characterization of the Gulf of Maine, Georges Bank, Scotian Shelf and neighboring continental slope. Gulf of Maine Area Program, Census of Marine Life. Website <http://www.gulfofmaine-census.org/about-the-gulf/physical-characteristics/bathymetry/hypsometric-characterization-of-the-gulf-of-maine-georges-bank-scotian-shelf/> (cited 01 December, 2010).

ITOPF (International Tanker Owners Pollution Federation). 2005. The use of chemical dispersants to treat oil spills. The International Tanker Owners Pollution Federation Limited, Technical Information Paper No. 4:1-8.

IUCN 2010. IUCN Red list of threatened species. Version 2010.1. Website <www.iucnredlist.org> (cited 23 April 2010).

Jacobs, R.P.W.M. and Marquenie, J.M. 1991. Produced water discharges from gas/condensate platforms: Environmental considerations. Presented at the 1st International Conference on Health, Safety and Environment. Society of Petroleum Engineers, Inc. SPE 23321. 98-96.

Jacobson, L.D. 2005. Essential fish habitat source document: Longfin inshore squid, *Loligo pealeii*, life history and habitat characteristics, 2nd Edition. NOAA Tech. Memo. NMFS-NE-193. 52pp.

James, M.C. and Herman, T.B. 2001. Feeding of *Dermochelys coriacea* on medusae in the Northwest Atlantic. Chelonian Conservation and Biology. 4:202-205.

James, M.C., Myers, R.A., and Ottensmeyer, C.A. 2005a. Behaviour of leatherback sea turtles, *Dermochelys coriacea*, during the migratory cycle. Proceedings of the Royal Society of London (B). 272:1547-1555.

James, M.C., Ottensmeyer, C.A., and Myers, R.A.. 2005b. Identification of high-use habitat and threats to leatherback sea turtles in northern waters: New directions for conservation. Ecological Letters. 8:195-201.

James, M.C., Sherrill-Mix, S.A., Martin, K., and Myers, R.A. 2006. Canadian waters provide critical foraging habitat for leatherback turtles. Biological Conservation. 133:347-357.

James, M.C., Sherrill-Mix, S.A., and Myers, R.A. 2007. Population characteristics and seasonal migrations of leatherback sea turtles at high latitudes. Marine Ecology Progress Series. 337:245-254.

Jamieson, G. and O'Boyle, R. 2001. Proceedings of the National Workshop on Objectives and Indicators for Ecosystem-based Management, Sidney, British Columbia, 27 February - 2 March 2001. DFO Can. Sci Advis. Sec. Proc. Rep. 2001/09. 140pp.

Jenkins, K.D., Howe, S. Saunders B.M. and Norwood, C. 1989. Sediment deposition, biological accumulation and subcellular distribution of barium following the drilling of an exploration well. IN Drilling Wastes. Engelhart, F.R., Ray, J., and Gillam, A.H. (eds). Elsevier Applied Sciences.

Jensen, C.F., Natanson, L.J., Pratt, H.L., Kohler, N.E., and Campana, S.E. 2002. The reproductive biology of the porbeagle shark (*Lamna nasus*) in the western North Atlantic Ocean. Fishery Bulletin. 100:727-738.

Ji, R., Cabell, D., Changseng, C., Townsend, D., Mountain, D., and Beardsley, R. 2008. Modeling the influence of low-salinity water inflow on winter-spring phytoplankton dynamics in the Nova Scotian Shelf-Gulf of Maine region. Journal of Plankton Research. 30:1399-1416.

Johnsen, S., Røe, T.I., Durell, G., and Reed, M. 1998. Dilution and bioavailability of produced water components in the northern North Sea. A combined modeling and field study. Presented at the 1998 SPE International Conference on Health, Safety and Environment in Oil and Gas Exploration and Production. Society of Petroleum Engineers, Inc. SPE 46578. 1-11.

Johnsen, S., Frost, T.K., Hjelsvold, M., and Utvik, T.R. 2000. The environmental impact factor – a proposed tool for produced water impact reduction, management and regulation. Society of Professional Engineers. Paper Number 61178.

Johnsen, S., Røe, T.I., Utvik, E., Garland, E., de Vals, B., and Campbell, J. 2004. Environmental fate and effects of contaminants in produced water. Presented at the 7th SPE International Conference on Health, Safety, and Environment in Oil and Gas Exploration and Production. Society of Petroleum Engineers, Inc. SPE 86708. 9pp.

Johnson, D.L., Morse, W.W., Berrien, P.L., and Vitaliano, J.J. 1999. Yellowtail flounder, *Limanda ferruginea*, life history and habitat characteristics. Essential fish habitat source document. NOAA Tech.Mem. NMFS-NE-140. 38pp.

Johnson, A.K., Richards, R.A, Cullen, D.W., and Sutherland, S.J. 2008. Growth, reproduction, and feeding of large monkfish, *Lophius americanus*. ICES Journal of Marine Science. 65:1305-1315.

Joyce, W.N., Campana, S.E., Natanson, L.J., Kohler, N.E., Pratt, H.L.Jr., and Jensen C.F.. 2002. Analysis of stomach contents of the porbeagle shark (*Lamna nasus* Bonnaterre) in the northwest Atlantic. ICES Journal of Marine Science. 59:1263-1269.

Kane, J. 2007. Zooplankton abundance trends on Georges Bank, 1977–2004. ICES Journal of Marine Science. 64: 909–919.

Kanwit, J.K. 2007. Tagging results from the 2000-2004 federal experimental fishery for Atlantic halibut (*Hippoglossus hippoglossus*) in the eastern Gulf of Maine. Journal of Northwest Atlantic Fishery Science. 38:37-42.

Karman, C. and Reerink, H.G. 1998. Dynamic assessment of the ecological risk of the discharge of produced water from oil and gas platforms. Journal of Hazardous Materials. 61:43-51.

Katona, S.K., Rough, V.R., and Richardson, D. 1993. A field guide to the whales and weals from Cape Cod to Newfoundland, 4th Edition (revised). Smithsonian Institution Press, Washington, D.C. 316pp.

Keevin, T.M. and Hempen, G.L. 1997. The environmental effects of underwater explosions with methods to mitigate impacts. Report of the U.S. Army Corps of Engineers, St. Louis District. 41pp.

Kenchington, E.L., Harding, G.C., Jones, M.W., and Prodohl, P.A. 2009. Pleistocene glaciation events shape genetic structure across the range of the American lobster, *Homarus americanus*. Molecular Ecology. 18:1654-1667.

Kennedy, E., L. Bennett, S. Campana, K. Clark, P. Comeau, M. Fowler, C. Gjerdrum, F. Gregoire, C. Hannah, L. Harris, G. Harrison, M. James, I. Jonsen, B. Law, G. Melvin, T. Milligan, S. Paul, D. Pezzack, J. Sameoto, J. Simon, K. Smedbol, P. Smith, H. Stone, D. Themelis, L. Van Eeckhaute, J. Wade, Y. Wang, and T. Worcester. 2011. The Marine Ecosystem of Georges Bank. DFO. Can. Sci. Advis. Sec. Res. Doc. 2011/059: xiv + 232pp.

Kenney, R.D. and Winn, H.E. 1986. Cetacean high use habitats of the Northeast United States continental shelf. Fishery Bulletin. 84:107-114.

Kenney, R.D., Scott, G.P., Thompson, T.J., and Winn, H.E. 1997. Estimates of prey consumption and trophic impacts of cetaceans in the USA northeast continental shelf ecosystem. Journal of Northwest Atlantic Fishery Science. 22:155-171.

Kennicutt, M.C. 1995. Gulf of Mexico offshore operations monitoring experiment, Phase I: sublethal responses to contaminant exposure (final report). Kennicutt, M.C.II (ed.). United States Department of the Interior, Minerals Management Service, Gulf of Mexico OCS Region, New Orleans, Louisiana. OCS Study MMS 95-0000. 705pp.

Kennicutt, M.C., Green, R.H., Montagna, P., and Roscigno, P.F. 1996. Gulf of Mexico offshore operations monitoring experiment (GOOMEX), Phase I: sublethal responses to contaminant exposure, introduction and overview. Canadian Journal of Fisheries and Aquatic Sciences. 53 2540-2553.

Ketos Ecology. 2007. Reducing the fatal entrapment of marine turtles in towed seismic survey equipment. Ketos Ecology Report. Website <www.Ketosecology.co.uk/KE2007.pdf> (cited 17 November 2010). 11pp.

Khan, R.A. and Payne, J.F. 2004. Comparative study of oil well drill cuttings and polycyclic aromatic hydrocarbons on parasitism in winter flounder: a dose-response study. Bulletin of Environmental Contamination and Toxicology. 73: 652-658.

Khelifa, A., Pahlow, M., Vezina, A., Lee, K., and Hannah, C. 2003. Numerical investigation of impact of nutrient inputs from produced water on the marine planktonic community. IN Proceedings of the 26th Arctic and marine Oilspill Program (AMOP) Technical Seminar. Environment Canada, Ottawa, Ontario. 323-334.

Khondaker, A.N. 2000. Modeling the fate of drilling waste in marine environment: an overview. Computer & Geosciences. 26:531-540.

Kidston, A.G., Brown, D.E., Smith, B., and Altheim, B. 2005. The Upper Jurassic Abenaki Formation, Offshore Nova Scotia: A Seismic and Geologic Perspective. Canada-Nova Scotia Offshore Petroleum Board, Halifax, Nova Scotia. 168pp.

Kidston, A.G., Smith, B., Brown, D.E., Makrides, C., and Altheim, B. 2007. Nova Scotia Deep Water Offshore Post-Drill Analysis: 1982-2004. Canada-Nova Scotia Offshore Petroleum Board, Halifax, Nova Scotia. 181pp.

King, S.C., Johnson, J.E., Haasch, M.L., Ryan, D.A., Ahokas, J.T., and Burns, K.A. 2005. Summary results from a pilot study conducted around an oil production platform on the Northwest Shelf of Australia. Marine Pollution Bulletin. 50:1163-1172.

Kingston, P. F. 1992. The impact of offshore oil production installations on the benthos of the North Sea. ICES Journal of Marine Science. 49:127-143.

Kiraly, S., Moore, J., and Jasinski, P. 2003. Deepwater and other sharks of the US Atlantic Ocean Exclusive Economic Zone. Marine Fisheries Review. 65:1-63.

Klein-MacPhee, G. 2002. Atlantic cod/*Gadus morhus* Linnaeus 1758. IN Bigelow and Schroeder's Fshes of the Gulf of Maine, 3rd Edition. Collette, B.B. and Klein-MacPhee, G. (eds.). Smithsonian Institution Press, Washington, D.C. 235-242

Knowlton, A.R., Kraus, S.D., and Kenney, R.D. 1994. Reproduction in North Atlantic right whales (*Eubalaena glacialis*). Canadian Journal of Zoology. 72:1297-1305.

Koh, R.C. and Chang, Y.C. 1973. Mathematical model for barged ocean disposal of waste. Technical Series EPA 660/2-73-29. U.S. Environmental Protection Agency, Washington, D.C.

Kohler, N.E., Turner, P.A., Hoey, J.J., Natanson, L.J., and Briggs, R. 2002. Tag and recapture data for three pelagic shark species: Blue shark (*Prionace glauca*), shortfin mako (*Isurus xyrinchus*), and porbeagle (*Lamna nasus*) in the north Atlantic ocean. Col. Vol. Sci. Pap. ICCAT. 54. 1231-1260.

Kostylev, V.E. and Hannah, C.G. 2007. Process-driven characterization and mapping of seabed habitats. IN Mapping the Seafloor for Habitat Characterization: Geological Association of Canada, Special Paper 47. Todd, B.J. and Greene, H.G. (eds.). 171-184.

Kostylev V.E., Todd, B.J., Longva, O., and Valentine, P.C. 2005. Characterization of benthic habitat on Northeastern Georges Bank, Canada. American Fisheries Society Symposium. 41:141-152.

Kraemer, T.F. and Reid, D.F. 1984. The occurrence and behavior of radium in saline formation water of the U.S. Gulf coast region. Isotope Geoscience. 2:153-174.

Kraus, S.D. and Rolland, R.M. 2007. Right whales in the Urban Ocean. IN The Urban Whale: North Atlantic Right Whales at the Crossroads. Kraus, S.D and Rolland, R.M. (eds.). Harvard University Press, Cambridge. 576pp.

Kraus, S.D., Prescott, J.H., Knowlton, A.R. and Stone, G.S. 1986. Migration and calving of right whales (Eubalaena glacialis) in the western North Atlantic. Report of the International Whaling Commission (Special Issue). 10:139-144.

Krause, P.R. 1995. Spatial and temporal variability in receiving water toxicity near an oil effluent discharge site. Archives of Environmental Contamination and Toxicology. 29:523-529.

Kurelec, B., Britvic, S., Rijavec, M., Muller, W.G., and Zahn, R.K. 1977. Benzo(a)pyrene monooxygenase induction in marine fish – molecular response to oil pollution. Marine Biology. 44:211-216.

Kvenvolden, K.A. and Harbaugh, J.W. 1983. Reassessment of the rates at which oil from natural sources enters the marine environment. Marine Environmental Research. 10:223-243.

Kvenvolden, K.A. and Cooper, C.K. 2003. Natural seepage of crude oil into the marine environment. Geo-Marine Letters. 23: 140–146.

Lai, D.Y. and Richardson, P.L. 1977. Distribution and movement of Gulf Stream rings. Journal of Physical Oceanography. 7:670-683.

Langton, R.W. 1983. Food habits of yellowtail flounder, *Limanda ferruginea* (Storer), from off the northeastern United States. Fishery Bulletin. 81:15-22.

Large, R. 1990. Characterization of produced water, phase 1: literature survey. Report to Conoco (UK) Ltd., Aberdeen, Scotland.

Lawson, J.W. and Gosselin, J.-F. 2009. Distribution and preliminary abundance estimates for cetaceans seen during Canada's marine megafauna survey - a component of the 2007 TNASS. DFO Can. Sci. Advis. Sec. Res. Doc. 2009/031. 34pp.

Lawson, J. and McQuinn, I. 2004. Review of the potential hydrophysical-related issues in Canada, risks to marine mammals, and monitoring and mitigation strategies for seismic activities. DFO Can. Sci. Advis. Sec. Res. Doc. 2004/121. 53pp.

LDEQ (Louisiana Department of Environmental Quality). 1990 (Unpublished data). Volumes, salinity, radium isotopes, and toxicity of produced water from coastal Louisiana. Source: M.T. Stephenson, Texaco Inc., Bellaire, Texas (received 10 February 2010). Microsoft Excel spreadsheet.

Le Gall, J.Y. 1974. Exposé synoptique des données biologiques sur le germon *Thunnus alalunga* (Bonaterre, 1788) de l'Océan Atlantique. Synopsis FAO sur les pêches, 109.

Leahy, J.G. and Colwell, R.R. 1990. Microbial-Degradation of Hydrocarbons in the Environment. Microbiological Reviews. 54:305-315.

Lee, K. 2000. In situ bioremediation of oiled shoreline environments. IN Opportunities for Advancement of Environmental Applications of Marine Biotechnology: Proceedings of the October 5-6, 1999, Workshop. The National Research Council of the National Academy of Sciences and the National Academy of Engineering. National Academy Press, Washington, D.C. 44-60.

Lee, K. 2002. Oil-particle interactions in aquatic environments: Influence on the transport, fate, effect and remediation of oil spills. Spill Science & Technology Bulletin. 8:3-8.

Lee, K. and De Mora, S. 1999. In situ bioremediation strategies for oiled shoreline environments. Environmental Technology. 20:783-794.

Lee, K. and Neff, J. 2011. Produced Water Discharge from Offshore Oil and Gas Facilities: Environmental Risks and Advances in Mitigation Technologies. Springer Publishing Company, New York. 492pp.

Lee, K. and Stoffyn-Egli, P. 2001. Characterization of oil-mineral aggregates. IN Proceedings of the 2001 International Oil Spill Conference. American Petroleum Institute, Washington D.C. 991-996.

Lee, K. and Tay, K.L. 1998. Measurement of microbial exoenzyme activity in sediments for environmental impact assessment. IN Microscale Aquatic Toxicology: Advances Techniques and Practice. Wells, P.G., Lee, K., and Blaise, C. (eds.). CRC Press, Inc. 219-236.

Lee, K., Tremblay, G.H., and Levy, E.M. 1993. Bioremediation: application of slow release fertilizers on low-energy shorelines. IN Proceedings of the 1993 International Oil Spill Conference. American Petroleum Institute, Washington, D.C. 449–454.

Lee, K., Siron, R., and Tremblay, G.H. 1995. Effectiveness of bioremediation in reducing toxicity in oiled intertidal sediments. IN Microbial Processes for Bioremediation. R.E. Hinchee, Vogel, C.M., and Brockman, F.J. (eds). Battelle Press, Columbus, Ohio. 117-127.

Lee, K., Stoffyn-Egli, P., and Owens, E.H. 2002. The OSSA II pipeline oil spill: Natural mitigation of a riverine oil spill by oil-mineral aggregate formation. Spill Science & Technology Bulletin. 7:149-154.

Lee, K., Stoffyn-Egli, P., Tremblay, G.-H., Owens, E.H., Sergy, G.A., Guenette, C.C., and Prince, R.C. 2003. Oil-mineral aggregate formation on oiled beaches: Natural attenuation and sediment relocation. Spill Science & Technology Bulletin. 8:285-296

Lee, K., Bain, H., and Hurley, G.V. 2005a. Overview of the Gully seismic research program. IN Acoustic Monitoring and Marine Mammal Surveys in the Gully and Outer Scotian Shelf Before and During Active Seismic Programs. Environmental Studies Research Funds Report No.151. Lee, K., Bain, H., and Hurley, G.V. (eds). Environmental Studies Research Funds, Calgary, Alberta. xi.

Lee, K., Azetsu-Scott, K., Cobanli, S.E., Dalziel, J., Niven, S., Wohlgeschaffen, G., and Yeats, P. 2005b. Overview of potential impacts of produced water discharges in Atlantic Canada. IN Offshore Oil and Gas Environmental Effects Monitoring: Approaches and Tecnhologies. Armsworthy, S.L., Cranford, P.J., and Lee K. (eds.). Battelle Press, Columbus, Ohio. 319-342.

Lee, K., Li, Z., King, T., Kepkay, P., Boufadel, M.C., and Venosa, A.D. 2008. Wave tank studies on formation and transport of OMA from the chemically dispersed oil. IN Oil Spill Response: A Global Perspective. Davidson, W.F., Lee, K., and Cogswell, A. (eds.). Springer, Netherlands. 159-177.

Lee, K., Li, Z., Boufadel, M.C., Venosa, A.D., and Scott Miles, M. 2009. Wave tank studies on dispersant effectiveness as a function of energy dissipation rate and particle size distribution. Final Report Submitted to NOAA/CRRC/UNH. 67+ App.

Lee, L.E.J. and Wright, M.A.R. 2009. Histopathological evaluation of hepatopancreas and ovaries from caged snow crabs, *Chionoecetes opilio,* fails to discern control and seismic exposed samples due to confounding effects from confinement, starvation and/or handling stress. IN Potential Impacts of Seismic Energy on Snow Crab: An Update to the September 2004 Peer Review. Courtenay, S.C., Boudreau, M., and Lee, K. (eds.). Environmental Studies Research Funds Report No. 178. Moncton. 181pp.

Lee, K., Armsworthy, S.L., Cobanli, S.E., Cochrane, N.A., Cranford, P.J., Drozdowski, A., Hamoutene, D., Hannah, C.G., Kennedy, E., King, T., Niu, H., Law, B.A., Li, Z., Milligan, T.G., Neff, J., Payne, J.F., Robinson, B.J., Romero, M., and Worcester, T. 2011. Consideration of the Potential Impacts on the Marine Environment Associated with Offshore Petroleum Exploration and Development Activities. DFO. Can. Sci. Advis. Sec. Res. Doc. 2011/060: xii + 136pp.

Lees, D.C. and Houghton, J.P. 1980. Effect of drilling fluids on benthic communities at the Lower Cook Inlet COST Well. IN Proceedings of Symposium, Research on Environmental Fate and Effects of Drilling Fluids and Cuttings, January 21-24, 1980, Lake Buena Vista, Florida. Vol I:209-350.

Legault, C.M., Alade, L., and Clark, K.J. 2009. Stock assessment of Georges Bank yellowtail flounder. TRAC Res. Doc. 2009/03.

Lehr, W.J. 2001. Review of the modelling procedures for oil spill weathering behaviour. IN Oil Spill Modeling and Processes. Brebbia, C.A. (ed.). WIT Press, Southhampton, United Kingdom. 161pp.

Levy, E.M. and Lee, K. 1988 Potential contribution of natural hydrocarbon seepage to benthic productivity and the fisheries of Atlantic Canada. Canadian Journal of Fisheries and Aquatic Sciences. 45:349-352.

Li, M.Z. and Amos, C.L. 2001. SEDTRANS96: The upgraded and better calibrated sediment-transport model for continental shelves. Computers and Geosciences. 27:619-645.

Li, W.K.W., Harrison, W.G., and Head, E.J.H. 2006. Coherent sign switching in multiyear trends of microbial plankton. Science. 311:1157-1160.

Li, W.K.W, Sieracki, M.E., Rooney-Varga, J.N., Martin, J.L., Wilson, W.H., Gifford, D.J., Pilskaln, C.H. Andersen, R.A., and Incze, L.S. 2009a. Planktonic microbes in the Gulf of Maine area. Census of Marine Life: Gulf of Maine microbial communities working group report. Gulf of Maine Science Symposium, St. Andrews, New Brunswick.

Li, Z., Lee, K., Robinson, B., and Ma, X. 2009b. Biodegradation of synthetic-based drilling muds in marine sediments. IN Proceedings of the 10th International In situ and On-site Bioremediation Symposium, May 5-8, 2009 Baltimore, Maryland. Batelle (ed.). Batelle, Columbus, Ohio.

Li, Z., Lee, K., King, T., Boufadel, M.C., and Venosa, A.D. 2009c. Evaluating chemical dispersion efficacy in an experimental wave tank: 2—significant factors determining *in situ* oil droplet size distribution. Environment Engineering Science. 26:1407-1418.

Li, Z., Lee, K., King, T., Boufadel, M.C., and Venosa, A.D. 2009d. Evaluating crude oil chemical dispersion efficacy in a flow-through wave tank under regular non-breaking wave and breaking wave conditions. Marine Pollution Bulletin. 58:735-744.

Limeburner, R. and Beardsley, R.C. 1996. Near-surface recirculation over Georges Bank. Deep Sea Research II. 43:1547-1574.

Link, J. 2002. Does food web theory work for mamine ecosystems? Marine Ecology Progress Series. 230:1-9.

Link, J. 2004. Using fish stomachs as samplers of the benthos: integrating long-term and broad scales. Marine Ecology Progress Series. 269:265-275.

Link, J., Almeida, F., Valentine, P., Auster, P., Reid, R., and Vitaliano, J. 2004. The effect of area closures on Georges Bank. IN Benthic Habitats and the Effects of Fishing. Barnes, P. and Thomas, J. (eds). American Fisheries Society, Bethesda, Maryland.

Link, J.S., O'Reilly, J., Dow, D., Fogarty, M., Vitaliano, J., Legault, C., Overholtz, W., Green, J., Palka, D., Guida, V., and Brodziak, J. 2008. Comparisons of the Georges Bank ecological network: EMAX in historical context. Journal of Northwest Atlantic Fishery Science. 39:83-101.

Lock, A.R., Brown, R.G.B., and Gerriets, S.H. 1994. Gazetteer of Marine Birds in Atlantic Canada. Canadian Wildlife Service, Ottawa, Ontario.

Loder, J.W., Brickman, D., and Horne, E.P.W. 1992. Detailed structure of currents and hydrography on the northern side of Georges Bank. Journal of Geophysical Research. 97:14331-14351.

Loder, J.W., K.R. Drinkwater, N.S. Oakey and E.P.W. Horne. 1993. Circulation, hydrographic structure and mixing at tidal fronts: the view from Georges Bank. Phil. Trans. R. Soc. London. 343: 447-460.

Loder, J.W., Hannah, C.G., Shen, Y. Gonzalez, E., and Xu, Z. 1998. Suspended sediment drift and dispersion on Georges Bank. Can. Tech. Rep. Hydro. Ocean Sci. 188pp.

Loder, J.W., Hannah, C.G., Petrie, B.D., and Gonzalez, E.A. 2003. Hydrographic and transport variability on the Halifax section. Journal of Geophysical Research. 108:8003-8021.

Løkkeborg, S., and Soldal, A.V. 1993. The influence of seismic exploration with air guns on cod (*Gadus morhua*) behaviour and catch rates. ICES Marine Science Symposia. 196:62-67.

Løkkeborg, S., Ona, E., Vold, A., Pena, H., Salthaug, A., Totland, B., Øvredal, J.T., Dalen, J., and Handegard, N.O. 2010. Effects of seismic surveys on fish distribution and catch rates of gillnets and longlines in Vesterålen in summer 2009. Institute of Marine Research. Report 2. Website <www.imr.no/filarkiv/2010/01/fh_2009-5_til_web.pdf/nb-no> (cited 27 October 2010). 50pp.

Lough, R.G. and Manning, J.P. 2001. Tidal-front entrainment and retention of fish larvae on the southern flank of Georges Bank. Deep-Sea Research II. 48:631-644.

Lough, R.G., Bolz, G.R., Pennington, M., and Grosslein, M.D. 1985. Larval abundance and mortality of Atlantic herring (Clupea harengus L.) spawned in the Georges Banks and Nantucket Shoals areas, 1971–1978 seasons, in relation to spawning stock size. Journal of Northwest Atlantic Fishery Science. 6:21-35.

Lough G., Valentine, P., Potter, D., Auditore, P., Bolz, G., Neilson, J., and Perry, I. 1989. Ecology and distribution of juvenile cod and haddock in relation to sediment type and bottom currents on eastern Georges Bank. Marine Ecology Progress Series. 56:1-12.

Lough, G.R. (ed.). 2004. Essential fish habitat source document: Atlantic cod, *Gadus morhus*, life history and habitat characteristics, 2nd EditionNOAA Tech. Mem. NMFS-NE-190. 104pp.

Lunel, T., Swannell, R., and Rusin, J. 1997. Monitoring the effectiveness of response operations during the Sea Empress incident: a key component of the successful. Oceanographic Literature Review. 44:1570-1570.

Lutcavage, M.E., Brill, R.W., Skomal, G.B., Chase, B.C., and Howey, P.W. 1999. Results of pop-up satellite tagging of spawning size class fish in the Gulf of Maine: Do North Atlantic bluefin tuna spawn in the mid-Atlantic? Canadian Journal of Fisheries and Aquatic Sciences. 56:173-177.

Lux, F.E. 1963. Identification of New England yellowtail flounder groups. Fishery Bulletin. 63:1-10.

Lynch, D.R., Gentleman, W.C., McGillicuddy, D.J., and Davis, C.S. 1998. Biological/physical simulations of *Calanus finmarchicus* population dynamics in the Gulf of Maine. Marine Ecology Progress Series. 169:189-210.

MacDonald, I.R. 1998. Natural oil spills. Scientific American. November 1998:57-61.

Mackay, D. 1991. Multimedia Environmental Models: The Fugacity Approach. Lewis Publishers Inc., Chelsea, Michigan. 261pp.

Maciolek, N.J. and Grassle, J.F. 1987. Variability of the benthic fauna. The seasonal variation 1981-82. IN Georges Bank. Backus, R.H. and Bourne, D.W. (eds.). MIT Press, Cambridge, Massachussetts. 303-309.

Madsen, P.T. 2005. Marine mammals and noise: Problems with root mean square sound pressure levels for transients. The Journal of the Acoustical Society of America. 117:3952 -3957.

Magnusson, J.V., Bergstad, O.A., Hareide, N.R., Magnusson, J., and Reinert, J. 1997. Ling, Blue Ling and Tusk of the Northeast Atlantic. Tema Nord 535.

Margesin, R., Labbe, D., Schinner, F., Greer, C.W., and Whyte, L.G. 2003. Characterization of hydrocarbon-degrading microbial populations in contaminated and pristine alpine soils. Applied and Environmental Microbiology. 69:3085-3092.

Mariani, G., Sick, L., and Johnson, C. 1980. An environmental monitoring study to assess the impact of drilling discharges in the Mid-Atlantic. III. Chemical and physical alterations in the benthic environment. IN Proceedings of Symposium, Research on Environmental Fate and Effects of Drilling Fluids and Cuttings, January 21-24, 1980, Lake Buena Vista, Florida.

MarineBio. 2006. Carretta caretta, Loggerhead Sea Turtle. Website <http://marinebio.org/species.asp?id=163> (cited 2 February 2010).

Martínez-Gómez, C., Fernández, B., Valdés, J., Campillo, J.A., Benedicto, J., Sánchez, F., and Vethaak, A.D. 2009. Evaluation of three-year monitoring with biomarkers in fish following the Prestige oil spill (N. Spain). Chemosphere. 74:613-620.

Mathieu, A. 2002. Potential impacts of exploratory drilling on the health and productivity of finfish and shellfish: A review Report by Oceans Ltd. (Report prepared for LGL). 25pp.

Mathieu, A., Melvin, W., French, B., Dawe, M., DeBlois, E.M., Power, F., and Williams, U. 2005. Health Effect Indicators in American plaice (*Hippoglossoides platissoides*) from the Terra Nova Development Site on the Grand Banks. IN Offshore Oil and Gas Environmental Effects Monitoring: Approaches and Tecnhologies. Armsworthy, S.L., Cranford, P.J., and Lee K. (eds.). Battelle Press, Columbus, Ohio. 297-317.

Mathieu, A., Hanlon, J., Myers, M., Melvin, W., French, B., DeBlois, E.M., King, T., Lee, K., Williams, U., Wight, F.M., and Janes, J. 2011. Studies on fish health around Terra Nova oil development site on the Grand Banks before and after release of produced water. IN Produced Water Discharge from Offshore Oil and Gas Facilities: Environmental Risks and Advances in Mitigation Technologies. Lee, K. and Neff, J. (eds.). Springer Publishing Company, New York. 492pp.

Maurer, D. 1983. Review of benthic invertebrates of Georges Bank in relation to gas and oil exploration with emphasis on management implications. National Marine Fisheries Service, Northeast Fisheries Center, Woods Hole, Massachusetts, Lab. Ref. Doc. 83-16. 329.

Maurer, D. and Leathem, W. 1980. Dominant species of polychaetous annelids of Georges Bank. Marine Ecology Progress Series. 3:135-144.

Maurer, D. and Leathem, W. 1981a. Ecological distribution of polychaetous annelids from the New England Shelf, Georges Bank. International Review of Hydrobiology. 66:505-528.

Maurer. D. and Leathem. W. 1981b. Polychaete feeding guilds from Georges Bank, USA. Marine Biology. 62:161-171.

Mayo, R.K. 1998. Pollock. IN Status of Fishery Resources off the Northeastern United States for 1998. Clark, S.H. (ed.). NOAA Tech. Memo. NMFS-NE-115:67-69.

Mayo, C.A. and Marx, M.K. 1990. Surface foraging behavior of the North Atlantic right whale, *Eubalaena glacialis*, and associated zooplankton characteristics. Canadian Journal of Zoology. 68:2214–2220.

Mayo, R.K. and Terceiro, M. 2005. Assessment of the 19 Northeast groundfish stocks through 2004. Northeast Fish. Sci. Cent. Ref. Doc. 05-13.

Mayo, R.K., McGlade, J.M., and Clark, S.H. 1989. Patterns of exploitation and biological status of pollock (*Pollachius virens*) in the Scotian Shelf, Georges Bank and Gulf of Maine area. Journal of Northwest Atlantic Fishery Science. 9:13-16.

Mayo, R.K., Broadziak, J.K.T., Burnett, J.M., Traver, M.L., and Col, L.A. 2007. The 2005 assessment of Acadian redfish, Sebastes fasciatus Storer, in the Gulf of Maine/GeorgesBank Region. Northeast Fish. Sci. Cent. Ref. Doc. 07-06.

McCauley, R.D., Fewtrell, J., Duncan, A.J., Jenner, C., Jenner, M-N., Penrose, J.D., Prince, R.I.T., Adhitya, A., Murdoch, J., and McCabe, K. 2000a. Seismic surveys: analysis and propagation of air-gun signals; and effects of air-gun exposure on humpback whales, sea turtles, fishes and squid. Australian Petroleum Production Exploration Association, Western Australia.

McCauley, R.D., Duncan, A.J., Penrose, J.D., Fewtrell, J., Jenner, C., Prince, R.T., Murdoch, J., and Adhitya, A. 2000b. Marine Seismic Surveys - a study of environmental implications. Australian Petroleum Production Exploration Association Journal.

McCauley, R.D., Fewtrell, J., and Popper, A.N. 2003. High intensity anthropogenic sound damages fish ears. Journal of the Acoustical Society of America. 113:638-642.

McCormack, P., Jones, P., Hetheridge, M.J., and Rowland, S.J. 2001. Analysis of Oilfield Produced Water and Production Chemicals by Electrospray Ionization Multistage MassSpectrometry (ESI-MSn). Water Research. 35:3567-3578.

McDonald, S.J., Willett, K.L., Thomsen, J.T., Beatty, K.B., Connor, K., Narasimhan, T.R., Erickson, C.M., and Safe, S.H. 1996. Sublethal detoxification responses to contaminant exposure associated with offshore production platforms. Canadian Journal of Fisheries and Aquatic Sciences. 53:2606-2617.

McEachern, J.D. 2002. Skates. Family Rajidae. IN Bigelow and Schroeder's Fishes of the Gulf of Maine, 3rd edition. Collette, B.B. and Klein-MacPhee, G. (eds.). Smithsonian Institution Press. Washington D.C. 60-75.

McEachern J.D, Boesch, D.F., and Musick, J.A. 1976. Food division within two sympatric species-pairs of skates (Pisces: Rajidae). Marine Biology. 35:301-317.

McIver, A.R. 1985. Environmental effects monitoring. Submission to the Hibernia Environmental Assessment Panel Public Hearing by Environment Canada, October 1985. 8p.

McQuinn, I.H. and Carrier, D. 2005. Far-field measurements of seismic airgun array pulses in the Nova Scotia Gully Marine Protected Area. IN Acoustic Monitoring and Marine Mammal Surveys in the Gully and Outer Scotian Shelf Before and During Active Seismic Programs. Environmental Studies Research Funds Report No.151. Lee, K., Bain, H., and Hurley, G.V. (eds). Environmental Studies Research Funds, Calgary, Alberta. 57-74.

McRuer, J., Halliday, R.G., Bramton, R.M., Showell, M.A., and Mohen, R. 1997. Status of witch flounder in Div 4VWX in 1997. DFO Can. Stock Assess. Sec. Res. Doc. 97/106. 41pp.

McRuer, J., Hurlbut, T., and Morin, B. 2000. Status of Wolffish (*Anarhichas lupus*) in the Maritimes (NAFO SubArea 4 and Division 5Ze). DFO Can. Stock Assess. Sec. Res. Doc. 2000/138. 55pp.

Means, J.L. and Hubbard, N. 1987. Short-chain aliphatic acid anions in deep subsurface brines: a review of their origin, occurrence, properties, and importance and new data on their distribution and geochemical implications in the Palo Duro Basin, Texas. Organic Geochemistry. 11:177-191.

Means, J.C., McMillin, D.J., and Milan, C.S. 1989. Characterization of produced water. IN Environmental Impact of Produced Water Discharges in Coastal Louisiana. Boesch, D.F and Rabalais, N.N. (eds.). Report to Mid-Continent Oil and Gas Association, New Orleans, Louisiana. 97-110.

Means, J.C., Milan C.S., and McMillin, D.J. 1990. Hydrocarbon and trace metal concentrations in produced water effluents and proximate sediments. IN An Assessment of Produced Water Impacts to Low-Energy, Brackish Water Systems in Southeast Louisiana. St. Pé, K.M. (ed.). Report to Louisiana Deptartment of Environmental Quality, Water Pollution Control Division, Lockport, Louisiana. 94-199

Meek, R.P. and Ray J.P. 1980. Induced sedimentation, accumulation and transport resulting from exploratory drilling discharges of drilling fluids and cuttings on the southern California Outer Continental Shelf. IN Proceedings of Symposium, research on environmental Fate and Effects of Drilling Fluids and Cuttings, January 21-24. 1980, Lake Buena Vista, Florida.

Meier, S., Andersen, T.E., Norberg, B., Thorsen, A., Taranger, G.L., Kjesbu, O.S., Dale, R., Morton, H.C., Klungsoyr, J., and Svardal, A. 2007. Effects of alkylphenols on the reproductive system of Atlantic cod (*Gadus morhua*). Aquatic Toxicology 81:207-218.

Melton, H.R., Smith, J.P., Martin, C.R., Nedwed, T.J., Mairs, H.L., and Raught, D.L. 2000. Offshore discharge of drilling fluids and cuttings - a scientific perspective on public policy. IN Rio Oil and Gas Conference. October 16-19, 2000, Rio de Janeiro, Brazil.

Melvin, G.D. and Stephenson, R.L. 2007. The dynamics of a recovering fish stock: Georges Bank herring. ICES Journal of Marine Science. 64:69–82.

Melvin, G.D., Stephenson, R.L., and Power, M.J. 2009. Oscillating reproductive strategies of Atlantic herring in response to changing environmental conditions. ICES Journal of Marine Science. 66:1784-1792.

Menzie, C., Maurer, D., and Leathem, W. 1980. An environmental monitoring study to assess the impact of drilling discharges in the Mid-Atlantic. IV. The effects of drilling discharges on the benthic community. IN Proceedings of Symposium, Research on Environmental Fate and Effects of Drilling Fluids and Cuttings, January 21-24, 1980, Lake Buena Vista, Florida.

Metaxas, A. and Davis, J. 2005. Megafauna associated with assemblages of deep-water gorgonian corals in Northeast Channel, of Nova Scotia, Canada. Journal of the Marine Biological Association of the United Kingdom. 85:1381-1390.

Methratta, E.T. and Link, J.S. 2006. Associations between surficial sediments and groundfish distributions in the Gulf of Maine–Georges Bank region. Norther American Journal of Fisheries Management. 26:473-489.

Michael, A.D., Long, C.D., Maurer D, and McGrath, R. 1983. Georges Bank benthic infauna historical study. Final Rep. to U.S. Dept of the Interior, Minerals Management Service, Washington, D.C. 171.

Michel, J. 1990. Relationship of radium and radon with geological formations. IN Uranium in Drinking Water. Cothern, C.R. and Ribers, P.A. (eds.). Lewis Publishers Inc., Chelsea, Michigan. 83-95.

Middleton, J.F. and Loder, J.W. 1989. Skew fluxes in polarized wave fields. Journal of Physical Oceaongraphy. 19:68-76.

Miller C.B., Lynch, D.R., Carlotti, F., Gentleman, W., and Lewis, C.V.W. 1998. Coupling of an individual-based population model of *Calanus finmarchicus* to a circulation model for the Georges Bank region. Fisheries Oceanography. 7:219-234.

Milligan, T.G. and Hill, P.S. 1998. A laboratory assessment of the relative importance of turbulence, particle composition, and concentration in limiting maximal floc size. Journal of Sea Research. 39:337-241.

Mitchell, E. and Chapman, D. G. 1977. Preliminary assessment of stocks of northwest Atlantic sei whales (*Balaenoptera borealis*). Report of the International Whaling Commission (Special Issue). 1:117-120.

MMS (U.S. Minerals Management Service). 1995. Technical Summary: Gulf of Mexico Offshore Monitoring Experiment (GOOMEX). MMS Publication 95-0045.

Moein, S.E., J.A. Musick, J.A. Keinath, D.E. Barnard, Lenhardt, M., and George, R. 1994. Evaluation of seismic sources for repelling sea turtles from Hopper dredges. Final report submitted to the U.S. Army Corps of Engineers Waterways Experiment Station (Report prepared by the Virginia Institute of Marine Sciences, Gloucester Point, Virginia).

Moody, J.A., Butman, B., Beardsley, R.C., Brown, W.S., Daifuku, P., Irish, J.D., Mayer, D.A., Mofjeld, H.O., Petrie, B., Ramp, S., Smith, P., and Wright, W.R. 1984. Atlas of tidal elevation and current observations on the Northeast American continental shelf and slope. United States Geological Survey Bulletin. 1611.

Moffitt, C.M., Rhea, M.R., Dorn, P.B., Hall, J.F., and Bruney, J.M. 1992. Short-term chronic toxicity of produced water and its variability as a function of sample time and discharge rate. IN Produced Water. Technological/Environmental Issues and Solutions. Ray, J.P. and Engelhardt, F.R. (eds.). Plenum Press, New York. 235-244.

Montagna, P.A. and Harper, D.E.Jr. 1996. Benthic infaunal long-term response to offshore production platforms in the Gulf of Mexico. Canadian Journal of Fisheries and Aquatic Sciences. 53:2567-2588.

Moreira-de-Gurjao, L., Pereira-de-Freitas, J.E., and Silva-Araújo, D. 2005. Observations of marine turtles during seismic surveys off Bahia, Northeastern Brazil. Marine Turtle News. 108:8–9.

Moriyasu, M., Allain, R., Benhalima, K., and Claytor, R. 2004. Effects of seismic and marine noise on invertebrates: a literature review. DFO Can. Sci. Advis. Sec. Res. Doc. 2004/126. 44pp.

Mortensen, P.B. and Buhl-Mortensen, L. 2004. Distribution of deep-water gorgonian corals in relation to benthic habitat features in the Northeast Channel (Atlantic Canada). Marine Biology. 144:1223-1238.

Mortensen, P.B., Buhl-Mortensen, L., Gass, S.E., Gordon, D.C.Jr., Kenchington, E.L.R., Bourbonnais, C., and MacIsaac, K.G. 2006. Deep-water corals in Atlantic Canada: A summary of ESRF-funded research (2001-2003). Environmental Studies Research Fund Report No. 143.

Mowbray, T.B. 2002. Northern Gannet (Morus bassanus). IN The Birds of North America, No. 693. Poole, A. and Gill, F. (eds.). The Birds of North America, Inc., Philadelphia, Pennsylvania.

Mrosovsky, N., Ryan, G., and James, M.C. 2009. Leatherback turtles: the menace of plastic. Marine Pollution Bulletin. 58:287-289.

Mukhtasor, Husian, T., Veitch, B., and Bose, N. 2004. An ecological risk assessment methodology for screening discharge alternatives of produced water. Human and Ecological Risk Assessment. 10:505–524.

Murray-Smith, R.J., Gore, D., Flynn, S.A., Vance, I., and Stagg, R. 1996. Development and appraisal of a particle tracking model for the dispersion of produced water discharges from an oil production platform in the North Sea. IN Produced Water 2: Environmental Issues and Mitigation Technologies. Reed, M. and Johnsen, S. (eds.). Plenum Press, New York. 225-245.

Murua, H. and Saborido-Rey, F. 2003. Female reproductive strategies of marine fish species of the North Atlantic. Journal of Northwest Atlantic Fishery Science. 33:23-31.

Muschenheim, D.K. and Lee, K. 2003. Removal of oil from the sea surface through particulate interactions: Review and prospectus. Spill Science and Technology Bulletin. 8:9-18.

Muschenheim, D.K. and Milligan, T.G. 1996. Flocculation and accumulation of fine drilling waste particulates on the Scotian Shelf (Canada). Marine Pollution Bulletin. 32:740-745.

Muschenheim, D.K. and Milligan, T.G. 1998. Benthic boundary layer processes and seston modification in the Bay of Fundy (Canada). Vie et Milieu. 48:285-294.

Muschenheim, D.K., Milligan, T.G., and Gordon, D.C.Jr. 1995. New technology and suggested methodologies for monitoring particulate wastes discharged from offshore oil and gas drilling platforms and their effects on the benthic boundary layer. Can. Tech. Rep. Fish. Aquat. Sci. 2049. 55pp

Myers, R.A., N.J. Barrowman, G. Mertz, J. Gamble and H.G. Hunt. 1994. Analysis of Continuous Plankton Recorder Data in the Northwest Atlantic 1959-1992. Can. Tech. Rep. Fish. Aquat. Sci. 1966. 248pp.

Myhre, L.P., Bausant, T., Sundt, R., Sanni, S., Vabø, R., Skjoldal, H.R., and Klungsøyr, J. 2004. Risk assessment of reproductive effects of alkyl phenols in produced water on fish stocks in the North Sea. Report prepared for the Norwegian OLF Oil Industry Association's Working Group for Discharges to Sea (Report prepared by RF-Akvamiljø and Institute of Marine Research). Report AM-2004/018. Website <www.imr.no/filarkiv/2004/08/AM_2004-018_Final_report_AP_risk_03112004_rev_3.pdf> (cited 21 October 2010). 81pp.

Myrberg, A.A.Jr. 2001. The acoustical biology of elasmobranchs. Environmental Biology of Fishes. 60:31-46.

Naimie, C.E. 1995. Georges Bank bimonthly residual circulation - prognostic numerical model results. Numerical Methods Laboratory, Dartmouth College, Hanover, New Hampshire. Rep No. NML-95-3. 33pp.

Naimie, C.E. 1996. Georges Bank residual circulation during weak and strong stratification periods - Prognostic numerical model results. Journal of Geophysical Research. 101:6469-6486.

Naimie, C.E., Loder, J.W., and Lynch, D.R. 1994. Seasonal variation of the three-dimensional residual circulation on Georges Bank. Journal of Geophysical Research. 99:5967- 5989.

Naimie, C.E., Limeburner, R., Hannah, C.G., and Beardsley, R.C. 2001. On the geographic and seasonal patterns of the near-surface circulation on Georges Bank – from real and simulated drifters. Deep-Sea Research II. 48:501-518.

Nazir, M., Khan, F., Amyotte, P., and Sadiq, R. 2008. Multimedia fate of oil spills in a marine environment- An integrated modeling approach. Process Safety and Environmental Protection. 86:141-148.

NDPSWG (Northeast Data Poor Stocks Working Group). 2009. The northeast data poor stocks working group report: Part A. skate species complex, deep sea red crab, Atlantic wolffish, scup, and black sea bass. December 8-12, 2008. Northeast Fish. Sci. Cent. Ref. Doc. 09-02. 38pp.

NEB (National Energy Board), Canada-Newfoundland and Labrador Offshore Petroleum Board, and Canada-Nova Scotia Offshore Petroleum Board. 2002. Offshore Waste Treatment Guidelines. Website <www.cnsopb.ns.ca/pdfs/owtg_redraft.pdf> (cited 27 October 2010). 21pp.

NEB (National Energy Board), Canada-Newfoundland and Labrador Offshore Petroleum Board, and Canada-Nova Scotia Offshore Petroleum Board. 2009. Guidelines Respecting the Selection of Chemicals Intended to be Used in Conjunction with Offshore Drilling and Production Activities on Frontier Lands.<www.cnsopb.ns.ca/call_for_bids_07_1/cnsopb/pdf/chemical guidelines.pdf> (cited 27 October 2010). 16pp.

Nedwed, T.J., Smith, J.P., and Brandsma, M.G. 2004. Verification of the OOC mud and produced water discharge model using lab-scale plume behavior experiments. Environmental Modelling and Software. 19:655-670.

Neff, J.M. 1987a. The potential effects of drilling effluents on marine organisms on George Bank. IN Georges Bank. Backus, R.H. and Bourne, D.W. (eds.). MIT Press, Cambridge, Massachusetts. 551-559.

Neff, J.M. 1987b. Biological effects of drilling fluids, drill cuttings and produced waters. IN Long-Term Effects of Offshore Oil and Gas Development. Boesch, D.F. and Rabalais, N.N. (eds.). Elsevier Applied Science Publishers, London. 469-538.

Neff, J.M. 1991. Technical review document: process waters in Cook Inlet, Alaska. Report to the Alaska Oil and Gas Association, Anchorage, Alaska.

Neff, J.M. 1997. Potential for bioaccumulation of metals and organic chemicals from produced water discharged offshore in the Santa Barbara Channel, California: A review. Report to the Western States Petroleum Association, Santa Barbara, California (Report prepared by Battelle Ocean Sciences, Duxbury, Massachussetts). 201pp.

Neff, J.M. 2002. Bioaccumulation in Marine Organisms. Effects of Contaminants from Oil Well Produced Water. Elsevier Science, Oxford, United Kingdom. 452pp.

Neff, J.M. 2005. Composition, environmental fates, and biological effect of water based drilling muds and cuttings discharged to the marine environment: A synthesis and annotated bibliography. Report prepared for the Petroleum Environment Research Forum (PERF). American Petroleum Institute, Washington, D.C. 73pp.

Neff, J.M. 2008. Estimation of bioavailability of metals from drilling mud barite. Integrated Environmental Assessment and Management. 4:184-193.

Neff, J.M. and Burns, W.A. 1996. Estimation of polycyclic aromatic hydrocarbon concentrations in the water column based on tissue residues in mussels and salmon: an equilibrium partitioning approach. Environmental Toxicology and Chemistry. 15:2240-2253.

Neff, J.M. and Foster, K. 1997. Composition, fates, and effects of produced water discharges to offshore waters of the Java Sea, Indonesia. Report to Pertimena/Maxus, Jakarta, Indonesia.

Neff, J.M., Rabalais, N.N., and Boesch, D.F. 1987. Offshore oil and gas development activities potentially causing long-term environmental effects. IN Long-Term Effects of Offshore Oil and Gas Development. Boesch, D.F. and Rabalais, N.N. (eds.). Elsevier Applied Science Publishers, London. 149-174.

Neff, J.M., Bothner, M., Maciolek, N., and Grassle, J. 1989a. Impacts of exploratory drilling for oil and gas on the benthic environment of Georges Bank. Marine Environmental Research. 27:77-114.

Neff, J.M., Sauer, T.C., and Maciolek, N. 1989b. Fate and effects of produced water discharges in nearshore marine waters. American Petroleum Institute, Washington, D.C. API Publication No. 4472. 300pp.

Neff, J.M., Johnsen, S., Frost, T., Røe Utvik, T., and Durell, G. 2006. Oil well produced water discharges to the North Sea. Part II: Comparison of deployed mussels (*Mytilus edulis*) and the DREAM Model to predict ecological risk. Marine Environmental Research. 62:224-246.

NEFSC (Northeast Fisheries Science Center). 2006a. 43rd northeast regional stock assessment workshop (43rd SAW): 43rd SAW assessment summary report. NEFSC Ref Doc. 06-14. 54pp.

NEFSC (Northeast Fisheries Science Center). 2006b. 42nd Northeast Regional Stock Assessment Workshop (42nd SAW) stock assessment report, part A: silver hake, Atlantic mackerel, and northern shortfin squid. Northeast Fish. Sci. Cent. Ref. Doc. 06-09a. 608pp.

NEFSC (Northeast Fisheries Science Center). 2007. 44th SAW Stock Assessment Report. Northeast Fish. Sci. Cent. Ref. Doc. 07-10. 36pp.

NEFSC (Northeast Fisheries Science Center). 2009. Ecosystem assessment report for the Northeast U.S. continental shelf large marine ecosystem. Ecosystem Assessment Program, Northeast Fish Sci Cent Ref Doc. 09-11.

Neilson, J.D. and Perley, P. 1996. Can ichthyoplankton data be used to describe spawning areas of marine fish? IN Report of the Second Workshop on Scotia-Fundy Groundfish Management. Burke, D.L, O'Boyle, R.N., Partington, P., and Sinclair. M. (eds.). Can. Tech. Rep. Fish. Aquat. Sci. 2100. 129-146.

Neilson, J.D., Hurley, P., and Perry, R.I. 1986. Stock structure of yellowtail flounder in the Gulf of Maine area: implications for management. CAFSAC Res. Doc. 86/64. Canadian Department of Fisheries and Oceans, Ottawa, Ontario.

Neilson, J.D., Perley, P., Carruthers, E.H., Stobo, W., and Clark, D. 2003. Stock structure of pollock in NAFO Divs. 4VWX5Zc. DFO Can. Sci. Advis. Sec. Res. Doc. 2003/045. 55pp.

Neilson, J.D., Stobo, W.T., and Perley, P. 2006. Pollock (*Pollachius virens*) stock structure in the Canadian Maritimes inferred from mark-recaprure studies. ICES Journal of Marine Science. 63:749-765.

Neilson, J.D., Paul, S.D., and Smith, S.C. 2007. Stock structure of swordfish (*Xiphias gladius*) in the Atlantic: a review of the non-genetic evidence. Coll. Vol. Sci. Pap. ICCAT. 61:25-60.

Neilson, J.D., Smith, S., Royer, F., Paul, S.D., Porter, J.M., and Lutcavage, M. 2009. Investigations of horizontal movements of Atlantic Swordfish using pop-up satellite archival tags. IN Tagging and Tracking of Marine Animals with Electronic Devices, Reviews: Methods and Technologies in Fish Biology and Fisheries. Nielsen, J.L., Arrizabalaga, H., Fragoso, N., Hobday, A., Lutcavage, M., and Sibert, J. (eds.). Springer, Netherlands. 9:400pp.

Nelson, R. 2009. A preliminary investigation into levels of naturally occurring radioactive materials (NORM) from offshore oil and gas production. International Produced Water Conference, Environmental Risks and Advances in Mitigation Technologies, October 17-18, 2007, St. John's, Newfoundland. Environmental Studies Funds Report. 43pp.

Nelson, G.A. and Ross, M.R. 1992. Distribution, growth and food habits of the Atlantic Wolffish (*Anarhichas lupus*) from the Gulf of Maine – Georges Bank region. Journal of Northwest Atlantic Fishery Science. 13:53-61.

NERC (Natural Environment Research Council). 1994. Report of the Plymouth Marine Laboratory. NERC. 70pp.

Nichols, W.J. and Venosa, A.D. 2008. Summary of the literature on the use of commercial bioremediation agents for cleanup of oil-contaminated environments. Proceedings of the 2008 International Oil Spill Conference. American Petroleum Institute, Washington, D.C. 1275-1280.

Nieukirk, S.L., Stafford, K.M., Mellinger, D.K., Dziak, R. P., and Fox, C.G. 2004. Low-frequency whale and seismic airgun sounds recorded in the mid-Atlantic Ocean. Journal of the Acoustical Society of America. 115:1832-1843.

Nishikawa, Y., Honma, M., Ueyanagi, S., and Kikawa, S. 1985. Average distribution of larvae of oceanic species of scombroid fishes, 1956-1981. Far Seas Fisheries Research Laboratory. 12pp.

Niu, H., Husain, T., Veitch, B., Bose, N., Adams, S., He, M., and Lee, K. 2007. Ocean outfall mapping using an Autonomous Underwater Vehicles. IN Proceedings of the MTS/IEEE Oceans 2007 Conference, September 29-October 4, 2007. Vancouver, British Columbia.

Niu, H., Drozdowski, A., Husain, T., Veitch, B., Bose, N., and Lee, K. 2008. Modeling the dispersion of drilling muds using the BBLT model: the effects of settling velocity. Environmental Modelling and Assessment. 14:585-594.

Niu, H., Husain, T., Veitch, B., Bose, N., Hawboldt, K., and Mukhtasor. 2009a. Assessing ecological risks of produced water discharge in a wavy marine environment. Advances in Sustainable Petroleum Engineering and Science. 1:1-11.

Niu, H., Lee, K., Husain, T., Veitch, B., and Bose, N. 2009b. The PROMISE model for evaluation of the mixing of produced water in marine environment. IN Proceedings of the 20th IASTED International Conference on Modelling and Simulation, July 6-8, 2009, Banff, Alberta.

Niu, H., Zhan, C., Lee, K., and Veitch, B. 2009c. Validation of a buoyant jet model (PROMISE) against laboratory data and other models. IN Proceedings of the IASTED International Conference on Modelling, Simulation and Identification, Oct 12-14, 2009, Beijing, China.

Niu, H., Adams, S., Lee, K., Husain, T., and Bose, N. 2009d. The application of autonomous underwater vehicles in offshore environmental effect monitoring. Journal of Canadian Petroleum Technology. 48:12-16.

Niu, H., Li, Z., Lee, K., Kepkay, P., and Mullin, J. 2010. A Method for Assessing Environmental Risks of Oil-Mineral-Aggregate to Benthic Organisms. Human and Ecological Risk Assessment. Human and Ecological Risk Assessment: An International Journal. 16(4):762-782.

Niu, H., Lee, K., and Husain, T. 2011. A Coupled Model for the Simulation of Produced Waters Dispersion in the Marine Environment. IN Produced Water Discharge from Offshore Oil and Gas Facilities: Environmental Risks and Advances in Mitigation Technologies. Lee, K. and Neff, J. (eds.). Springer Publishing Company, New York. 492pp.

NOAA (National Oceanic and Atmospheric Administration). 2006. Loggerhead Turtle (Caretta caretta). Website <www.nmfs.noaa.gov/pr/species/turtles /loggerhead.htm> (cited 2 February 2010).

NOAA (National Oceanic and Atmospheric Administration). 2008. Trends in spring conditions for the Georges Bank subregion, ecosystem advisory for the northeast shelf large marine ecosystem, no 2. Website <http://www.nefsc.noaa.gov/omes/OMES/spring2008/adv3.2.1.html> (cited 3 February 2010).

Nordeide J.T. and Kjellsby, E. 1999. Sounds from spawning cod at their spawning grounds. ICES Journal of Marine Science. 56:326-332.

Nozaki, Y. 1991. The systematics and kinetics of U/Th decay series nuclides in ocean water. Reviews in Aquatic Sciences. 4:75-105.

NRC (National Research Council). 1989. National Research Council :Using oil spill dispersant on the sea. National Academy Press, Washington D.C.

NRC (National Research Council). 2003a. Ocean Noise and Marine Mammals. The National Academies Press: Washington, D.C. 204pp.

NRC (National Research Council). 2003b. National Research Council: Oil in the Sea III: Inputs, Fates and Effects. The National Academies Press: Washington, D.C. 395pp.

NRC (National Research Council). 2005. Marine Mammal Populations and Ocean Noise – Determining when Noise Causes Biologically Significant Effects. The National Academies Press: Washington, D.C. 142pp.

NRCan and NSPD (Natural Resources Canada and Nova Scotia Petroleum Directorate). 1999. Georges Bank Review Panel Report. Ottawa, Ontario: Queen's Printer for Canada. 83pp.

NRT (U.S. National Response Team Science & Technology Committee). 2000. NRT fact sheet: bioremediation in oil spill response. U.S. National Response Team. Environmental Protection Agency. Website <www.nationalresponseteam.org/production/NRT/NRTWeb.nsf/AllAttachmentsByTitle/A-78bioremedFS/$File/bioremed_FS.pdf?OpenElement> (cited 25 October 2010). 3pp.

O'Brien, L. and Worcester, T. 2009. Transboundary Resources Assessment Committee eastern Georges Bank cod benchmark assessment. TRAC Proceedings 2009/02.

O'Brien, L., Burnett, J., and Mayo, R.K. 1993. Maturation of nineteen species of finfish off the northeast coast of the United States, 1985-1990. NOAA Tech. Rep. NMFS-NE-113. 72pp.

O'Dor, R.K. and Balch, N. 1985. Properties of *Illex illecebrosus* egg masses potentially influencing larval oceanographic distribution. NAFO Science Council Studies. 9: 69-76.

OGP (International Association of Oil and Gas Producers). 2002. Aromatics in produced water: occurrence, fate and effects and treatments. OGP Publications, Report No. 1.20/324. 24pp.

OGP (International Association of Oil and Gas Producers). 2004. Environmental performance in the E&P industry. OGP Publications, 2003 Data Report No. 359. 32pp.

O'Hara, J. and Wilcox, J.R. 1990. Avoidance responses of loggerhead turtles, *Caretta caretta*, to low frequency sound. Copeia. 2: 564-567.

Ohman M.D., Durbin, E.G., Runge, J.A., Sullivan, B.K., and Field, D.B. 2008. Relationship of predation potential to mortality of *Calanus finmarchicus* on Georges Bank, northwest Atlantic. Limnology and Oceanography. 53:1643-1655.

Oldham, W.S. 1966. Some aspects of the fishery and life history of the cusk (*Brosme brosme* (Muller). Master of Science Thesis, University of Western Ontario, London, Ontario. 86pp.

Oldham, W.S. 1972. Biology of Scotian Shelf cusk, *Brosme brosme*. International Commission for the Northwest Atlantic Fisheries Research Bulletin. 9:85-98.

OLF (The Norweigian Oil Industry Association). 2004. Seismic surveys and fish. Report published by the Norweigian Oil Industry Association, Stavanger, Norway. 6pp.

Olsgard, F. and Gray, J.S. 1995. A comprehensive analysis of effects of offshore oil and gas exploration and production on the benthic communities of the Norwegian continental shelf. Marine Ecology Progress Series. 122: 277-306.

OOC (Offshore Operators Committee). 1997. Definitive component technical report. Gulf of Mexico produced water bioaccumulation study. Report to OOC, New Orleans, Louisiana (Report prepared by Continental Shelf Associates, Inc., Jupiter, Florida).

O'Reilly, J.E. and Busch, D.A. 1984. Phytoplankton primary production of the northwestern Atlantic shelf. Rapports et Proces-Verbaux des Reunions. 183:255-268.

O'Reilly, J.E., Evans-Zetlin, C., and Busch, D.A. 1987. Primary Production. IN Georges Bank. Backus, R.A. and Bourne, D.W. (eds.). MIT Press, Cambridge, Masschussets. 220-233.

O'Reilly, J.E., Sauer, T.C., Ayers, R.C. Jr., Brandsma, M.G., and Meek, R. 1989. Field validation of the OOC mud discharge model. IN Drilling Wastes. Proceedings of the 1988 International Conference on Drilling Wastes. April 5-8, 1989, Calgary, Alberta. Engelhardt, F.R., Ray, J., and Gillam A.H. (eds). Elsevier.

Orentas, N. 2000. Avanti Corporation. Memorandum to Charles Tamulonis, U.S. EPA, EAD, regarding preliminary analysis of benthic faunal sample data collected during the EPA/Industry SBF screening cruise, August 1997.

Otto, G.H. and Arnold, K.E. 1996. U.S. produced water discharge regulations have tough limits. Oil & Gas Journal. 94:54-61.

Overholtz, W.J., Jacobson, L.J., Melvin, G.D., Cieri, M., Power, M.J., Libby, D., and Clark, K. 2004. Stock assessment of the Gulf of Maine-Georges Bank herring stock complex, 2003. NFSC Ref. Doc. 04-06. 300pp.

Owens, E.H., Sergy, G.A., Guenette, C.C., Prince, R.C., and Lee, K. 2003. The reduction of stranded oil by in situ shoreline treatment options. Spill Science and Technology Bulletin. 8:257-272.

Packer, D.B, Zetlin, C.A, and Vitaliano, J.J. (eds.). 2003a. Essential fish habitat source document: Winter skate, *Leucoraja ocellatta*, life history and habitat characteristics. NOAA Tech. Mem. NMFS-NE-179. 68pp.

Packer, D.B, Zetlin, C.A, and Vitaliano, J.J. (eds.). 2003b. Essential fish habitat source document: Little skate, *Leucoraja erinacea*, life history and habitat characteristics. NOAA Tech. Mem. NMFS-NE-175. 75pp.

Packer, D.B, Zetlin, C.A, and Vitaliano, J.J. (eds.). 2003c. Essential fish habitat source document: Thorny skate, A*mblyraja radiata*, life history and habitat characteristics. NOAA Tech. Mem. NMFS-NE-178. 39pp.

Packer, D.B, Zetlin, C.A, and Vitaliano, J.J. (eds.). 2003d. Essential fish habitat source document: Smooth skate, *Malacoraja senta*, life history and habitat characteristics. NOAA Tech. Mem. NMFS-NE-177. 26pp.

Packer, D.B, Zetlin, C.A, and Vitaliano, J.J. (eds.). 2003e. Essential fish habitat source document: Barndoor skate, *Dipturus laevis*, life history and habitat characteristics. NOAA Tech. Mem. NMFS-NE-173. 23pp.

Page, F.H., Losier, R., and Berrien P. 1998. Spawning time of haddock and cod on Georges Bank as indicated by the MARMAP ichthyoplankton data set. DFO Can. Stock Assess. Sec. Res. Doc. 97/130. 26pp.

Page, F.H., Losier, R., Drinkwater, K., Petrie, B., Harrison, G., and Sameoto, D. 2001. Overview of the physical and biological oceanographic conditions on Georges Bank. DFO Can. Sci. Advis. Sec. Res. Doc. 2001/66. 35pp.

Palka, D., Read, A., and Potter, C. 1997. Summary of knowledge of white-sided dolphins *(Lagenorhynchus acutus*) from the U.S. and Canadian North Atlantic waters. Report of the International Whaling Commission. 47:729-34.

Parent, S., Pepin, S., Genet, J-P., Misserey, L., and Rojas, S. 2008. Captive breeding of the barndoor skate, *Dipturus laevis*, at the Montreal Biodome, with comparison notes on two other captive-bred skate species. Zoo Biology. 27:145-153.

Parente, C.L.; Lontra. J.D., and Araújo, M.E. 2006. Occurrence of sea turtles during seismic surveys in northeastern Brazil. Biota Neotropica. 6:13pp.

Parry, G.D. and Gason, A. 2006. The effect of seismic surveys on catch rates of rock lobsters in western Victoria, Australia. Fisheries Research. 79:272-284.

Patin, S. 1999. The Environmental Impact of the Offshore Oil and Gas Industry. EcoMonitor Publishing, New York. 425pp. + App.

Payne, J.F. 2004. Potential effect of seismic surveys on fish eggs, larvae and zooplankton. DFO Can. Sci. Advis. Sec. Res. Doc. 2004/125. 12pp.

Payne, J.F. 2007. A population approach to fish monitoring: too much blind trust? Integrated Environmental Assessment and Management. 3:299-301.

Payne, J.F. and Fancey, L.L. 1989. Effect of polycyclic aromatic hydrocarbons on immune responses in fish: change in melanomacrophage centers in flounder (*Pseudopleuronectes americanus*). Marine Environmental Research. 28:431-435.

Payne, J.F., Bauld, C., Dey, A.C., Kiceniuk, J.W., and Williams, U. 1984. Selectivity of mixed-function oxygenase enzyme induction in flounder (*Pseudopleuronectes americanus*) collected at the site of the Baie Verte, Newfoundland oil spill. Comparative Biochemistry and Physiology. 79C:15-19.

Payne, J.F., Fancey, L., Rahimtula, A., and Porter, E. 1987. Review and perspective on the use of mixed-function oxygenase enzymes in biological monitoring. Comparative Biochemistry and Physiology. 86C:233-245.

Payne, J.F., Kiceniuk, J.W.L., Fancey, L.L, Williams, U.P., Fletcher, G.L., Rahimtula, A., and Fowler, B. 1988. What is a safe level of polycyclic aromatic hydrocarbons for fish: subchronic toxicity study on winter flounder (*Pseudopleuronectes americanus*). Canadian Journal of Fisheries and Aquatic Sciences. 45:1983-1993.

Payne, J.R., McNabb, G.D., and Clayton, J.R Jr. 1991. Oil-weathering behavior in Arctic environments. Polar Research. 10: 631-662.

Payne, J.F., Fancey, L.L., Hellou, J., King, M.J., and Fletcher, G.L. 1995. Aliphatic hydrocarbons in sediments: a chronic toxicity study with winter flounder *(Pleuronectes americanus)* exposed to hydrocarbon-contaminated sediments. Canadian Journal of Fisheries and Aquatic Sciences. 52:2724-2735.

Payne, J., Fancey, L., Andrews, C., Meade, J., Power, F., Lee, K., Veinott, G., and Cook, A. 2001a. Laboratory exposures of invertebrate and vertebrate species to concentrations of IA-35 (Petro-Canada) drill mud fluid, production water and Hibernia drill mud cuttings. Can. Data Rep. Fish. Aquat. Sci. 2560. 27pp.

Payne, J., Andrews, C., Whiteway, S., and Lee, K. 2001b. Definition of sediment toxicity zones around oil development sites: dose response relationships for the monitoring surrogates Microtox® and amphipods, exposed to Hibernia source cuttings containing a synthetic based oil. Can. Manuscr. Rep. Fish. Aquat. Sci. 2577. 10pp.

Payne, J.F., Mathieu, A., and Collier, T.K. 2003. Ecotoxicological studies focusing on marine and freshwater fish. IN Polycyclic Aromatic Hydrocarbons: an Ecotoxicological Perspective Douben. P.E.T. (ed.). John Whiley and Sons, London. 192-224.

Payne, J.F., Andrews, C.D., Guiney, J.M., and Lee, K. 2005. Production water releases on the Grand Banks: potential for endocrine and pathological effects in fish. IN Proceedings of the 32nd Annual Toxicity Workshop, October 3-5, Waterloo, Ontario .Dixon, D.G., Munro, S., and Niimi, A.J. (eds.). Can. Tech. Rep. Fish. Aquat. Sci. 2617. 138pp.

Payne, J.F., Andrews, C., Guiney, J., and Whiteway, S. 2006. Risks associated with drilling fluids at petroleum development sites in the offshore: Evaluation of the potential for an aliphatic hydrocarbon based drilling fluid to produce sedimentary toxicity and for barite to be acutely toxic to plankton. Can. Tech. Rep. Fish. Aquat. Sci. 2679. 28pp.

Payne, J.F., Andrews, C.A., Fancey, L.L., Cook, A.L., and Christian, J.R. 2007. Pilot study on the effect of seismic air gun noise on lobster (*Homarus americanus*). Can. Tech. Rep. Fish. Aquat. Sci. 2712. v + 46pp.

Payne, J.F., Andrews, C.A., Fancey, L.L., Guiney, J., Cook, A.L., and Christian, J.R. 2008a. Are seismic surveys an important risk factor for fish and shellfish? Bioacoustics. 17:262-265.

Payne, J.F., Andrews, C., Fancey, L., White, D., and Christian, J. 2008b. Potential effects of seismic energy on fish and shellfish: an update since 2003. DFO Can. Sci. Advis. Sec. Res. Doc. 2008/060. 20pp.

Pearson, W.J., Skalski, J.R., and Malme, C.I. 1992. Effects of sounds from a geophysical survey device on behaviour of captive rockfish (*Sebastes* sp.). Canadian Journal of Fisheries and Aquatic Sciences. 49:1343-1356.

Penttila, J.A. and Gifford, V.M. 1976. Growth and mortality rates for cod from the Georges Bank and Gulf of Maine areas. International Commission for the Northwest Atlantic Fisheries Research Bulletin. 12:29-36.

Pereira, J.G. 1995. Etat d'exploitation du stock de patudo. Collect. Vol. Sci. Pap, ICCAT. 44:272-280.

Pérez-Casanova, J.C., Hamoutene, D., Samuelson, S., Burt, K., King, T.L., and Lee, K. 2010. The immune response of juvenile Atlantic cod (*Gadus morhua L.*) to chronic exposure to produced water. Marine Environmental Research. 70(1):26-34.

Pershing, A. J., Greene, C.H., Jossi, J.W., O'Brien, L., Brodziak, J.K.T., and Bailey, B.A. 2005. Interdecadal variability in the Gulf of Maine zooplankton community, with potential impacts on fish recruitment. ICES. Journal of Marine Science. 62:1511-1523.

Peterson, C.H., Kennicutt, M.C. II, Green, R.H., Montagna, P., Harper, D.E. Jr., Powell, E.N., and Roscigno, P.F. 1996. Ecological consequences of environmental perturbations associated with offshore hydrocarbon production: a perspective from study of long-term exposures in the Gulf of Mexico. Canadian Journal of Fisheries and Aquatic Sciences. 53:2637–2654.

Petrie, B.D. and Drinkwater, K.F. 1993. Temperature and salinity variability on the Scotian Shelf and in the Gulf of Maine 1945-1990. Journal of Geophysical Research. 98:20,079-20,089.

Pezzack, D.S. and Duggan, D.R. 1987. Canadian offshore lobster fishery, 1985-86, and assessment of the potential for future increases in catch. Can. Atl. Fish. Adv. Comm. Res. Doc. 87/79. 25pp.

Pezzack, D.S., Frail, C.M., Tremblay, M.J., and Reeves, A. 2009. Offshore lobster LFA 41 (4X and 5Zc). DFO Can. Sci. Advis. Sec. Res. Doc 2009/023. 124pp.

Phillips, C.R., Payne, J.R., Lambach, J.L., Farmer, G.H., and Sims, R.R.Jr. 1987. Georges bank monitoring program: hydrocarbons in bottom sediments and hydrocarbons and trace metals in tissues. Marine Environmental Research. 22:33-74.

Pierotti, R.J. 1988. Associations between marine birds and mammals in the Northwest Atlantic Ocean. IN Seabirds and Other Marine Vertebrates. Burger, J. (ed.). Columbia University Press, New York. 31-58.

Pierotti, R.J. and Good, T.P. 1994. Herring gull (*Larus argentatus*). IN The Birds of North America, No. 124. Poole, A. and Gill, F. (eds.). The Birds of North America, Inc., Philadelphia, Pennsylvania.

Pikanowski, R.A., Morse, W.W., Berrien, P.L., Johnson, D.L., and McMilliam, D.G. 1999. Essential fish habitat source document: Redfish, *Sebastes* spp., life history and habitat characteristics. NOAA Tech. Mem. NMFS-NE-132. 28pp.

Pitt, T.K. 1967. Diurnal variation in the catches of American plaice, *Hippoglossoides platessoides*, from the Grand Bank. ICNAF Research Bulletin. 4:53-58.

Pivel, M.A.G., Freitas, C.M.D.S., and Comba, J.L.D. 2009. Modeling the discharges of cuttings and drilling fluids in a deep-water environment. Deep-Sea Research II. 56:12-21.

Popper, A.N. 2003. Effects of anthropogenic sounds on fishes. Fisheries. 28:24-31.

Potter, J.R., Chitre, M., Seekings, P., and Douglas, C. 2005. Marine mammal monitoring and seismic source signal analysis: EnCanna's Stonehouse 3-D seismic survey, 2003. IN Acoustic Monitoring and Marine Mammal Surveys in the Gully and Outer Scotian Shelf Before and During Active Seismic Programs. Environmental Studies Research Funds Report No.151. Lee, K., Bain, H., and Hurley, G.V. (eds). Environmental Studies Research Funds, Calgary, Alberta. 41-56.

Potter, S. and Buist, I. 2008. In-situ burning for oil spills in Arctic waters: State-of-the-art and future research needs. IN Proceedings of the NATO CCMS Workshop on Oil Spill Response, October 11-13, 2006, Dartmouth, Nova Scotia. Davidson, W.F., Lee, K., and Cogswell, A. (eds). Springer Science, The Netherlands. 23-39.

Powers, K.D. and Brown R.G.B. 1987. Seabirds. IN Georges Bank. Backus, R.H. and Bourne, D.W. (eds.). The MIT Press, Cambridge, Massachusetts. 359-371.

Pratt, H.L. 1979. Reproduction in the blue shark, *Prionace glauca*. Fishery Bulletin. 77:445-470.

Price, J. M., Johnson, W.R., Marshall, C.F., Ji, Z.G., and Rainey, G.B. 2003. Overview of the Oil Spill Risk Analysis (OSRA) Model for Environmental Impact Assessment. Spill Science & Technology Bulletin. 8:529-533.

Prince, R.C. 1993. Petroleum spill bioremediation in marine environments. Critical Reviews in Microbiology. 19:217-242.

Prince, R.C. 2010. Eukaryotic hydrocarbon degraders. IN Handbook of Hydrocarbon and Lipid Microbiology. Timmis, K.N. (ed). Springer Berlin, Heidelberg. 2065-2078.

Prince, R.C. and Clark, J.R. 2004 Bioremediation of marine oil spills. In Petroleum Biotechnology—Studies in Surface Science and Catalysis (Vol. 151). Vazquez-Duhalt, R. and Quintero-Ramirez, R. (eds.). Elsevier, Amsterdam. 495–512.

Prince, R.C., Garrett, R.M., Bare, R.E., Grossman, M.J., Townsend, T., Suflita, J.M., Lee, K., Owens, E.H., Sergy, G.A., Braddock, J.F., Lindstrom, J.E., and Lessard, R.R. 2003a. The Roles of Photooxidation and Biodegradation in Long-term Weathering of Crude and Heavy Fuel Oils. *Spill Science and Technology Bulletin*. 8:145-156.

Prince, R.C., Bare, R.E., Garrett, R.M., Grossman, M.J., Haith, C.E., Keim, L.G., Lee, K., Holtom, G.J., Lambert, P., Sergy, G.A., Owens, E.H., Guenette, C.C. 2003b. Bioremediation of stranded oil on an arctic shoreline. Spill Science and Technology Bulletin. 8:303-312.

Procter, R.M., Taylor, G.C., and Wade, J.A. 1984. Oil and natural gas resources of Canada - 1983. Geological Survey of Canada Paper 83-31. 59pp.

Querbach, K., Maillet, G., Cranford, P.J., Taggart, C., Lee, K., and Grant, J. 2005. Potential effects of produced water discharges on the early life stages of three resource species. IN Offshore Oil and Gas Environmental Effects Monitoring: Approaches and Tecnhologies. Armsworthy, S.L., Cranford, P.J., and Lee K. (eds.). Battelle Press, Columbus, Ohio. 343-372.

Rabalais, N.N., McKee, B.A., Reed, D.J., and Means, J.C. 1991. Fate and effects of nearshore discharges of OCS produced waters. U.S. Department of the Interior, Minerals Management Service, Gulf of Mexico OCS Regional Office, New Orleans, Louisiana. OCS Studies MMS 91-004, MMS 91-005, and MMS 91-006.

Ramachandran, S.D., Hodson, P.V., Khan, C.W., and Lee, K. 2004. Oil dispersant increases PAH uptake by fish exposed to crude oil. Ecotoxicology and Environmental Safety. 59:300-308.

Ray, J.P. and Meek, R.P. 1980. Water column characterisation of drilling fluids dispersion from an offshore exploratory well on Tanner Bank. IN Proceedings Symposium on Research on Environmental Fate and Effects of Drilling Fluids and Cuttings, Lake Buena Vista, Florida. American Petroleum Institute, Washington, D.C.

Reed, J.K. 2002. Deep-water *Oculina* coral reefs of Florida: biology, impacts, and management. Hydrobiologia. 471:43-55.

Reed, M. and Spaulding, M.L. 1984. Response of Georges Bank cod to periodic and nonperiodic oil spill events. Environmental Management. 8:67-74.

Reed, M., Johnsen, S., Melbye, A., and Rye, H. 1996. PROVANN a model system for assessing potential chronic effects of produced water. IN Produced Water 2. Environmental Issues and Mitigation Technologies (Environmental Science Research, Volume 52). Reed, M. and Johnsen, S. (eds.). Plenum Press, New York. 317-330.

Reed, M., Johansen, Ø., Brandvik, P.J., Daling, P., Lewis, A., Fiocco, R., Mackay, D., and Prentki, R. 1999. Oil spill modelling toward the close of the 20th century: overview of the state of the art. Spill Science and Technology Bulletin. 5:3-16.

Reed, M., Daling, P.S., Brakstad, O.G., Singsaas, I., Faksness, L., Hetland, B., and Ekrol, N. 2000. OSCAR2000: A multi-component 3-dimensional oil spill contigency and response model. IN Proceedings of the 23rd Arctic and marine Oilspill Program (AMOP) Technical Seminar. Environment Canada, Ottawa, Ontario.

Reed, M., Rye, H., Johansen, Ø., Johnsen, S., Frost, T., Hjelsvold, M., Karman, C., Smit, M., Giacca, D., Bufagni, M., Gauderbert, B., Durrieu, J., Utvik, T.R., Follum, O.A., Sanni, S., Skadsheim, A., Bechham, R., and Bausant, T. 2001. DREAM: A dose-related exposure assessment model - Technical description of physical-chemical fates components. IN Proceedings of the 5th International Marine Environmental Modeling Seminar, October 9-11, 2001, New Orleans, Louisiana.

Reed, M., Daling, P., Lewis, A., Ditlevsen, M.K., Brørs, B., Clark, J., and Aurand, D. 2004. Modeling of dispersant application to oil spills in shallow coastal waters. Environmental Modelling & Software. 19:681-690.

Reid, D.F. 1983. Radium in formation waters: how much and is it a concern? IN 4th Annual Gulf of Mexico Information Transfer Meeting, New Orleans, Louisiana. U.S. Department of the Interior, Minerals Management Service, Gulf of Mexico OCS Office, New Orleans, Louisiana. 187-191.

Reid, R., Almeida, F., and Zetlin, C. 1999. Essential fish habitat source document: Fishery independent surveys, data sources and methods. NOAA Tech. Mem. NMFS-NE-122. 39pp.

Richards, W.J. 1969. Distribution and relative apparent abundance of larval tunas collected in the tropical Atlantic during Equalant surveys I and II. Proc. Symp. Oceanogr. Fish. Resourc. Trop. Atl.-Rev. Contrib. Pap. UNESCO, Paris, Pap. 25: 289-315.

Richards, W.J. 1984. Kinds and abundances of fish larvae in the Caribbean Sea and adjacent areas. NOAA Technical Report NMFS-SSRF-776. 1-54.

Richards, R.A., Nitschke, P.C., and Sosebee, K.A. 2008. Population biology of monkfish *Lopius americanus.* ICES Journal of Marine Science. 65:1291-1305.

Richardson, W.J., Greene, C.R.Jr., Malme, C.I., and Thomson, D.H. 1995. Marine Mammals and Noise. Academic Press, San Diego, California. 576pp.

Ridderinkhof, H. and Loder, J.W. 1994. Lagrangian characterization of circulation over submarine banks with application to the outer Gulf of Maine. Journal of Physical Oceanography. 24:1184-1200.

Rittenhouse, G., Fulton III, R.B., Grabowski, R.J., and Bernard, J.L. 1969. Minor elements in oil field waters. Chemical Geology. 4:189-209.

Rivkin, R.B., Tian, R., Anderson, M.R., and Payne, J.F. 2000. Ecosystem level effects of offshore platform discharges: Identification, assessment and modelling. IN Proceedings of the 27th Annual Toxicity Workshop: October 1-4, 2000, St. John's, Newfoundland. Penney, K.C., Coady K.A., Murdoch, M.H., Parker, W.R., and Niimi, A.J. (eds.). Can. Tech. Rep. Fish. Aquat. Sci. 2331. 3-12.

Robards, M.D., Willson, M.F., Armstrong, R.H., and Piatt, J.F. 1999. Sand lance: a review of biology and predator relations and annotated bibliography. Res. Pap. PNW-RP-521. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station.

Røe Utvik, T.I., Durell, G.S., and Johnsen, S. 1999. Determining produced water originating polycyclic aromatic hydrocarbons in North Sea waters: comparison of sampling techniques. Marine Pollution Bulletin. 38:977-989.

Ronconi, R. 2007. The spectacular migration of greater shearwaters. Birdwatch Canada. 39:4-7.

Rooker, J.R., Secor, D.H., De Metrio, G., Schloesser, R., Block, B.A., and Neilson, J.D. 2008. Natal homing and connectivity in Atlantic bluefin tuna populations. Science. 322:742-744.

Rosenberg, E., Lagmann, R., Kushmaro, A., Taube, R., Adler, R., and Ron, E.Z. 1992. Petroleum bioremediation-a multiphase problem. Biodegradation. 3:337-350.

Ross, C., Belford, S.L., and Fudge, S.M. 2003. Review of SOEI's Offshore EEM Program. Presented at the Offshore Oil and Gas Environmental Effects Monitoring Workshop: Approaches and Technologies, May 26-29, 2003, Bedford Institute of Oceanography Dartmouth, Nova Scotia.

Rowe, S. and Hutchings, J. 2006. Sound production by Atlantic cod during spawning. Transactions of the American Fisheries Society. 135:529–538.

Royce, W.F., Buller, R.J., and Premetz, E.D. 1959. Decline of the yellowtail flounder (*Limanda ferruginea*) off New England. Fishery Bulletin. 59:169-267.

Rubega, M.A., Schamel, D., and Tracy, D.M. 2000. Red-necked phalarope (*Phalaropus lobatus*). IN The Birds of North America, No. 538. Poole, A. and Gill, F. (eds.). The Birds of North America, Inc., Philadelphia, Pennsylvania.

Rye, H. Reed, M., Durgut, I., and Ditlevsen, M.K. 2006a. Documentation report for the revised DREAM model. ERMS Report No. 18. SINTEF Report No. STF80MK F06224. Website <http://www.sintef.no/Home/Freetext-search/> cited (19 October 2010).

Rye, H., Johansen, Ø., Durgut, I., Reed, M., and Ditlevsen, M.K. 2006b. Restitution of an impacted sediments. ERMS Report No. 21. SINTEF Report No. STF80MK F06226. Website <http://www.sintef.no/Home/Freetext-search/> cited (19 October 2010).

Rye, H., Reed, M., Frost, T.K., Smit, M.G., Durgut, I., Johansen, O., and Ditlevsen, M.K. 2008. Development of a numerical model for calculating exposure to toxic and nontoxic stressors in the water column and sediment from drilling discharges. Integrated Environmental Assessment and Management. 4:194-203.

Sabeur, Z.A. and Tyler, A.O. 2000. Development of a vew generation modelling system for the prediction of the behaviour and impact of dffshore discharges to the marine environment. IN Proceedings of the SPE Health, Safety and Environment in Oil and Gas Exploration and Production Conference, June 26-28, 2000, Stavanger, Norway.

Santschi, P.H. and Honeyman, B.D. 1989. Radionuclides in aquatic environments. Radiation Physics & Chemistry. 34:213-240.

Schein, A., Scott, J.A., Mos, L., and Hodson, P.V. 2009. Oil dispersion increases the apparent bioavailability and toxicity of diesel to rainbow trout (*Oncorhynchus mykiss*). Environmental Toxicology and Chemistry. 28:595-602.

Schrey, A. and Heist, E. 2003. Microsatellite analysis of population structure in the shortfin mako (*Isurus oxyrinchus*). Canadian Journal of Fisheries and Aquatic Sciences. 60:670-675.

Schuck, H.A. and Arnold, E.L. 1951. Comparison of haddock from Georges and Browns bank. Fishery Bulletin. 52:177-185.

Scott, J.S. 1982. Depth, temperature and salinity preferences of common fishes of the Scotian Shelf. Journal of Northwest Atlantic Fishery Science. 3:29-39.

Scott, W.B. and Scott, M.G. 1988. Atlantic fishes of Canada. Canadian Bulletin of Fisheries and Aquatic Sciences No. 219.

Sergy, G.A., Guenette, C.C., Owens, E.H., Prince, R.C., and Lee, K. 2003. In-situ Treatment of Oiled Sediment Shorelines. Spill Science and Technology Bulletin. 8:237-244.

SFSC (Southeast Fisheries Science Center). 2009. An assessment of loggerhead sea turtles to estimate impacts of mortality reductions on population dynamics. NMFS Southeast Fisheries Science Center Contribution PRD-08/09-14, July, 2009, 46p.

Shagaeva, V.G., Nikol'skaya, M.P., Akimova, N.V., Markov, K.P., and Nikol'skaya, N.G. 1993. A study of the early ontogenesis in the Volga sturgeon (Acipenseridae) in connection with anthropogenic effects. Journal of Ichthyology. 33:230-240 (Russian).

Shaw, D.G., Farrington, J.W., Connor, M.S., Trippm, B.W., and Schubel, J.R. 1999. Potential environmental consequences of petroleum exploration and development on Grand Banks. New England Aquarium Aquatic Forum Series Report 00-3, Boston, Massachussetts. 64pp.

Shemer, H. and Linden, K.G. 2007. Aqueous photodegradation and toxicity of the polycyclic aromatic hydrocarbons fluorine, dibenothiofuran and dibenzothiopene. Water Research. 41:853-861.

Shepard, F.P., Trefethen, J.M., and Cohee, G.V. 1934. Origin of Georges Bank. Geological Society of America Bulletin. 45:281-302.

Sherman, K., Smith, W.G., Green, J.R., Cohen, E.B., Berman, M.S., Marti, K.A., and Goulet, J.R. 1987. Zooplankton production and the fisheries of the Northeastern Shelf. IN Georges Bank. Backus R.A. and Bourne, D.W. (eds.). MIT Press, Cambridge, Massachussetts. 268-282.

Sherrill-Mix, S.A., James, M.C., and Myers, R.A. 2008. Migration cues and timing in leatherback sea turtles. Behavioral Ecology. 19:231-236.

Shirihai, H.,0 and Jarrett, B. 2006. Whales Dolphins and Other Marine Mammals of the World. Princeton University Press, Princeton, New Jersey. 384pp.

Shoop, C.R. and Kenney, R.D. 1992. Seasonal distributions and abundances of sea turtles off the northeastern United States. Herpetological Monographs. 6:43-67.

Sieburth J.M., Smetecek, V., and Lenz, J. 1978. Pelagic ecosystem structure: Heterotrophic compartments of plankton and their relationship to plankton size fractions. Limnology and Oceanography. 23:1256-1263.

Sigourney, D.B., Ross, M.R., Brodziak, J., and Burnett, J. 2006. Length at age, sexual maturity and distribution of Atlantic halibut, *Hippoglossus hippoglossus* L., off the Northeast USA. Journal of Northwest Atlantic Fishery Science. 36:81-90.

Simard, Y., Samaran, F., and Roy, N. 2005. Measurement of whale and seismic sounds in the Scotian Gully and adjacent canyons in July 2003. IN Acoustic Monitoring and Marine Mammal Surveys in the Gully and Outer Scotian Shelf Before and During Active Seismic Programs. Environmental Studies Research Funds Report No.151. Lee, K., Bain, H., and Hurley, G.V. (eds). Environmental Studies Research Funds, Calgary, Alberta. 97-116.

Simon, J.E. and Frank, K.T.. 1998. Assessment of the winter skate fishery in Division 4VsW. DFO Can. Stock Assess. Sec. Res. Doc.98/145. 41pp.

Simon, J.E., Harris, L.E., and Johnston, T.L. 2003. Distribution and abundance of winter skate, *Leucoraja ocellatta*, in the Canadian Atlantic. DFO Can. Sci. Advis. Sec. Res. Doc. 2003/028. 70pp.

Simon J.E., Cook, A., Rowe, S., and Simpson, M. 2009. Pre-COSEWIC review of barndoor skate (*Dipturus laevis*) in the Canadian Atlantic. DFO Can. Sci. Advis. Sec. Res. Doc. 2009/084. 93pp.

Singsaas, I., Rye, H., Frost, T.K., Smit, M.G., Garpestad, E., Skare, I., Bakke, K., Veiga, L.F., Buffagni, M., Follum, O.A., Johnsen, S., Moltu, U.E., and Reed, M. 2008. Development of a risk-based environmental management tool for drilling discharges. Summary of a four-year project. Integrated Environmental Assessment and Management. 4:171-176.

Sir Alister Hardy Foundation for Ocean Science (SAHFOS). 2005. Website <http://192.171.163.165/index.htm> (cited 28 January 2010).

Skalski, J.R., Pearson, W.H., and Malme, C.I. 1992. Effects of sounds from a geophysical survey device on catch-per-unit-effort in a hook-and-line fishery for rockfish (*Sebastes* spp.). Canadian Journal of Fisheries and Aquatic Sciences. 49:1357-1365.

Skåtun, H.M.1996. A buoyant jet/plume model for subsea releases. IN Produced Water 2: Environmental Issues and Mitigation Technologies. Reed, M. and Johnsen, S. (eds.). Plenum Press, New York. 247-255.

Sklepkovych, B.O. and Montevecchi, W.A. 1989. The world's largest documented colony of Leach's storm-petrels on Baccalieu Island, Newfoundland. American Birds. 43:36-42.

Skognes, K. and Johansen, Ø. 2004. Statmap – a 3-dimensional model for oil spill risk assessment. Environmental Modelling & Software. 19:727-737.

S.L. Ross Environmental Research Ltd. 1995. The behaviour and fate of gas and condensate spills from the Sable Offshore Energy Project. Report to Mobil Oil Canada Properties 21 pp.

Smit, M.G., Jak, R.G., Rye, H., Frost, T.K., Singsaas, I., and Karman, C.C. 2008. Assessment of environmental risks from toxic and nontoxic stressors; a proposed concept for a risk-based management tool for offshore drilling discharges. Integrated Environmental Assessment and Management. 4:177-183.

Smith, P.C. 1978. Low-frequency fluxes of momentum, heat salt and nutrients at the edge of the Scotian Shelf. Journal of Geophysical Research. 83:4079-4096.

Smith, J. and May, S.J. 1991. Ula Wellsite 7/12-9 environmental survey 1991. A report to SINTEF SI (Report prepared by the Field Studies Council Research Centre).

Smith, J.P., Mairs, H.R., Brandsma, M.G., Meek, R.P., and Ayers, R.C. 1994. Field validation of the Offshore Operators Committee (OOC) produced water discharge model. Society of Petroleum Engineers, Inc. SPE paper No. 28350,

Smith, J.P., Tyler, A.O., Rymell, M.C., and Sidharta, H. 1996. Environmental impacts of produced waters in the Java Sea, Indonesia. IN 1998 SPE Asia Pacific Oil and Gas Conference, October 28-30, 1996, Adelaide, Australia. SPE 37002.

Smith, P.C., Flagg, C.N., Limeburner, R., Fuentes-Yaco, C., Hannah, C.G., Beardsley, R.C., and Irish, J.D. 2003. Scotian Shelf crossovers during winter/spring 1999. Journal of Geophysical Research. 108:8013. 31pp.

Smith, J.P., Brandsma, M.G., and Nedwed, T.J. 2004. Field verification of the Offshore Operators Committee (OOC) mud and produced water discharge model. Environmental Modelling Software. 19:739-749.

SOEP (Sable Offshore Energy Project). 1996. Sable Offshore Energy Project Environmental Impact Statement. Canada Nova Scotia Offshore Petroleum Board. 481pp.

Soldal, A.V., Midling, K.Ø., Fosseidengen, J.E., Svellingen, I., and Øvredal, J.T. 2000. Fish sound, a future tool for selectivity. Paper given at Fifth European Conference on Underwater Acoustics. Lyon, France, July 10-13, 2000.

Somerville, H.J., Bennett, D., Davenport, J.N., Holt, M.S., Lynes, A., Mahieu, A., McCourt, B., Parker, J.G., Stephenson, R.R., Watkinson, R.J., and Wilkinson T.G. 1987. Environmental effect of produced water from North Sea oil operations. Marine Pollution Bulletin. 18:549-558.

Southall, B.L., Bowles, A.E., Ellison, W.T., Finneran, J.J., Gentry, R.L., Greene, C.R., Kastak, D., Ketten, D.R., Miller, J.H., Nachtigall, P.E., Richardson, W.J., Thomas, J.A., and Tyack, P.L. 2007. Marine mammal noise exposure criteria: Initial scientific recommendations. Aquatic Mammals. 33:411-522.

Spaulding, M.L. 1988. A state-of-the-art review of oil spill trajectory and fate modelling. Oil and Chemical Pollution. 4:39-55

Spaulding, M.L. 1994. "MUDMAP": A numerical model to predict drill fluid and produced water dispersion. Offshore (Houston Texas issue).

Spaulding, M.L., Saila, S.B., Lorda, E., Walker, H.A., Anderson, E.L., and Swanson, J.C. 1983. Oil spill fishery interaction modelling: Application to selected Georges Bank fish species. Estuarine, Coastal and Shelf Science. 16:511-541.

Spaulding, M.L., Reed, M., Anderson, E., Isaji, T., Swanson, J.C., Saila, S., Lorda, E., and Walker, H. 1985. Oil spill fishery impact assessment model: Sensitivity to spill location and timing. Estuarine, Coastal and Shelf Science. 20:41-53.

Stagg, R.M. and McIntosh, A. 1996. Hydrocarbon concentrations in the northern North Sea and effects on fish Larvae. The Science of the Total Environment. 186:189-201.

Stagg, R.M., McIntosh, A., and Mackie, P. 1995. Elevation of hepatic monooxygenase activity in the Dab (*Limanda limanda L.*) in relation to environmental contamination with petroleum hydrocarbons in the northern North Sea. Aquatic Toxicology. 33:245-264.

Stafford, K.M., Fox, C.G., and Clark, D.S. 1998. Long-range acoustic detection and localization of blue whale calls in the northeastern Pacific Ocean. Journal of the Acoustical Society of America. 104:3616-3625.

Stebbing, A.R.D., Dethlefsen, V., and Carr, M. 1992. Biological effects of contaminants in the North Sea: results of the ICES/IOC Bremerhaven workshop. Marine Ecology Progress Series. 91:361pp.

Steele, J.H., Collie, J.S., Bisagni, J.J., Gifford, D.J., Fogarty, M.J., Link, J.S., Sullivan, B.K., Sieracki, M.E., Beet, A.R., Mountain, D.G., Durbin, E.G., Palka, D., and Stockhausen, W.T. 2007. Balancing end-to-end budgets of the Georges Bank ecosystem. Progress in Oceanography. 74:423-448.

Stehlik, L.L. 1993. Diets of the brachyuran crabs Cancer irroratus, C. borealis and Ovalipes ocellatus in the New York Blight. Journal of Crustacean Biology. 13:723-735.

Stehilk, L.L., Mackenzie, C.L.Jr., and Morse, W.W. 1991. Distribution and abundance of four brachyuran crabs on the northwest Atlantic Shelf. Fishery Bulletin. 86:473-492.

Steimle, F.W., Morse, W.W., and Johnson, D.L. 1999. Essential fish habitat source document: Goosefish, *Lopius americanus*, life history and habitat characteristics. NOAA Tech. Mem. NMFS-NE-127. 40pp.

Steimle, F.W., Zetlin, C.A, and Chang, S. 2001. Essential Fish Habitat Source Document: Red Deepsea Crab, *Chaceon (Geryon) quinquedens*, Life History and Habitat Characteristics. NOAA Tech. Mem. NEFSC NMFS-NE-163. 36pp.

Stephenson, M.T. 1991. Components of produced water: A compilation of results from several industry studies. IN Proceedings of the SPE Health, Safety and Environment in Oil and Gas Exploration and Production Conference, November 10-14, 1991, Hague, The Netherlands. Society of Petroleum Engineers, Inc. SPE 23313. 25-38.

Stephenson, M.T. 1992. A survey of produced water studies. IN Produced Water. Technological/Environmental Issues and Solutions. Ray, J.P. and Engelhardt, F.R. (eds.). Plenum Press, New York. 1-11

Stephenson, M.T., Ayers, R.C., Bickford, L.J., Caudle, D.D., Cline, J.T., Cranmer, G., Duff, A., Garland, E., Herenius, T.A., Jacobs, R.P.W.M., Inglesfield, C., Norris, G., Petersen, J.D., and Read, A.D. 1994. North Sea produced water: fate and effects in the marine environment. E&P Forum, London, England. Report No. 2.62/204. 48pp.

Stevenson, D.K. and Scott, M.L. 2005. Essential fish habitat source document: Atlantic herring, *Clupea harengus*, life history and habitat characteristics, 2nd Ed. NOAA Tech Memo NMFS-NE-192. 94pp.

Stoecker, D.K., Taniguchi, A. and Nichaels, A.E. 1989. Abundance of autotrophic, mixotrophic and heterotrophic planktonic ciliates in shelf and slope waters. Marine Ecology Progress Series. 50:241-254.

Stone, H.H. and Nelson, C. 2003. Tagging studies on eastern Georges Bank yellowtail flounder. DFO Can. Sci. Advis. Sec. Res. Doc. 2003/056. 22pp.

Stone, C.J. and Tasker, M.L. 2006. The effects of seismic airguns on cetaceans in UK waters. Journal of Cetacean Research and Management. 8:255-263.

Stone, H., Gavaris, S., Legault, C.M., Neilson, J.D., and Cadrin, S.X. 2004. Collapse and recovery of the yellowtail flounder (*Limanda ferruginea*) fishery on Georges Bank. Journal of Sea Research. 51:261-270.

Stone, H.H., Nelson, C., Clark, D., and Cook, A. 2009. 2008 Assessment of Pollock in 4VWX+5. DFO Can. Sci. Advis. Sec. Res. Doc. 2009/001. 87pp.

Strømgren, T., Sørstrøm, S.E., Schou, L., Kaarstad, I., Aunaas, T., Brakstad, O.G., and Johansen, Ø. 1995. Acute toxic effects of produced water in relation to chemical composition and dispersion. Marine Environmental Research. 40:147-169.

Studholme, A.L., Packer, D.B., Berrien, P.L., Johnson, D.L., Zetlin, C.A., and Morse W.W. 1999. Essential fish habitat source document: Atlantic mackerel, *Scomber scombrus*, life history and habitat characteristics. NOAA Tech. Memo. NMFS-NE-141. 44pp.

Sturve, J., Hasselberg, L., Falth, H., Celander, M.C., and Forlin, L. 2006. Effects of North Sea oil and alkylphenols on biomarker responses in juvenile Atlantic cod (*Gadus morhua*). Aquatic Toxicology. 78:573-578.

Sulikowski, J.A., Morin, M.D., Suk, S.H., and Howell, W.H. 2003, Age and growth estimates of the winter skate (*Leucoraja ocellatta*) in the western Gulf of Maine. Fishery Bulletin. 101:405-413.

Sullivan B.K. and Meise, C.J. 1996. Invertebrate predators on Georges Bank, 1977-1978. Deep-Sea Research II. 43:1503-1519.

Swain, D.P., Simon, J.E., Harris, L.E., and Benoît, H.P. 2006. Recovery potential assessment of 4T and 4VW winter skate (*Leucoraja ocellata*): biology, current status and threats. DFO Can. Sci. Advis. Sec. Res. Doc. 2006/003. 69pp.

Swannell, R.P.J., Lee, K., and McDonagh, M. 1996. Field Evaluations of Oil Spill Bioremediation. Microbiological Reviews. 60:342-365.

TAWG (Turtle Assessment Working Group). 2007. An assessment of the leatherback turtle population in the Atlantic Ocean. NOAA Tech. Mem. NMFS-SEFSC-555. 116pp.

Templeman, W. 1985. Stomach contents of Atlantic Wolffish (*Anarhichas lupus*) from the Northwest Atlantic. NAFO Sci. Coun. Studies. 8:49-51.

Terrens, G.W. and Tait, R.D. 1993. Effects on the marine environment of produced formation water discharges from Esso/BHPP's Bass Strait Platforms. Esso Australia Ltd., Melbourne, Australia. 25pp.

Terrens, G.W. and Tait, R.D. 1994. Effects on the marine environment of produced formation water discharges from offshore development in Bass Strait, Australia. SPE Advanced Technology Series. 4:42-50.

Terrens, G.W. and Tait, R.D. 1996. Monitoring ocean concentrations of aromatic hydrocarbons from produced formation water discharges to Bass Strait, Australia. IN Proceedings of the International Conference on Health, Safety & Environment. Society of Petroleum Engineers, Inc. SPE 36033. 739-747.

Terrens, G.W., Gwyther, D., Keough, M.J., and Tait, R.D. 1998. Environmental assessment of synthetic based drilling mud discharges to Bass Strait, Australia. IN Proceedings of the SPE Health, Safety and Environment in Oil and Gas Exploration and Production Conference, June 7-10, 1998, Caracas, Venezuela. Society of Petroleum Engineers, Inc. SPE 46622. 1-14.

Theroux, R.B. and Grosslein, M.D. 1987. Benthic fauna. IN Georges Bank. Backus, R. H. and Bourne, D.W. (eds.). MIT Press, Cambridge, Massachussetts. 283-295.

Theroux, R.B. and Wigley, R.L. 1998. Quantitative composition and distribution of the macrobenthic invertebrate fauna of the Continental Shelf ecosystems of the Northeastern United States. NOAA Technical Report NMFS 140. 246pp.

Thomas, A., Townsend, D., and Weatherbee, R. 2003. Satellite-measured phytoplankton variability in the Gulf of Maine. Continental Shelf Research. 23:971-989.

Thomas, L., Hammill, M.O., and Bowen, W.D. 2007. Estimated size of the Northwest Atlantic grey seal population 1977-2007. DFO. Can. Sci. Advis. Sec. Res. Doc. 2007/082. 31pp.

Thompson, D. and Härkönen, T. 2008. *Phoca vitulina*. IUCN Red List of Threatened Species. Version 2009.2. Website <www.iucnredlist.org> (cited February 2010).

Thouzeau, G., Robert, G., and Ugarte, R. 1991. Faunal assemblages of benthic megainvertebrates inhabiting sea scallop grounds from eastern Georges Bank, in relation to environmental factors. Marine Ecology Progress Series. 74:61-82.

Tian, R.C., Chen, C., Stokesbury, K.D.E., Rothschild, B.J., Cowles, G.W., Xu, Q., Hu, S., Harris, B.P., and Marino, M.C.II. 2009. Modeling the connectivity between sea scallop populations in the Middle Atlantic Bight and over Georges Bank. Marine Ecology Progress Series. 380:147-160.

Tissot, B.N., Yoklavich, M.M., Love, M.S., York, K., and Amend, M. 2006. Benthic invertebrates that form habitat structures on deep banks off southern California, with special reference to deep sea coral. Fishery Bulletin. 104:167-181.

Tkalich, P. and Chan, E.S. 2002. Vertical mixing of oil droplets by breaking waves. Marine Pollution Bulletin. 44:1219-1229.

Tomczyk, N.A., Winans, R.W., Shinn, J.H., and Robinson, R.C. 2001. On the nature and origin of acidic species in petroleum. 1. Detailed acid type distribution in a California crude oil. Energy & Fuels. 15:1498-1504.

Townsend, D.W., Thomas, A.C., Mayer, L.M., Thomas, M.A., and Quinlan, J.A. 2006. Oceanography of the Northwest Atlantic continental shelf (1,W). IN The Sea, Volume 14A. Robinson, A.R. and Brink, K.H. (eds.). Harvard University Press, Cambridge, Massachussetts. 119-168.

Townsend, D.W, Rebuck, N.D., Thomas, M.A., Karp-Boss, L., and Gettings, R.M. 2009. A changing nutrient regime in the Gulf of Maine. Gulf of Maine Symposium 2009: Advancing ecosystem research for the future of the Gulf. Oct. 4-9, 2009, St. Andrews, New Brunswick.

TRAC (Transboundary Resources Assessment Committee). 2009a. Gulf Of Maine-Georges Bank Herring Stock Complex. TRAC Status Report 2009/04. 6pp.

TRAC (Transboundary Resources Assessment Committee). 2009b. Eastern Georges Bank Cod. TRAC Status Report 2009/01. 7pp.

TRAC (Transboundary Resources Assessment Committee). 2009c. Eastern Georges Bank Haddock. TRAC Status Report 2009/02. 6pp.

TRAC (Transboundary Resources Assessment Committee). 2009d. Georges Bank yellowtail flounder. TRAC Status Report 2009/03. 8pp.

Tracy, D.M., Schamel, D., and Dale, J. 2002. Red Phalarope (*Phalaropus fulicarius*). IN The Birds of North America, No. 698. Poole A. and Gill, F. (eds.). The Birds of North America, Inc., Philadelphia, Pennsylvania.

Tremblay, M.J. and Sinclair, M. 1990. Sea scallop larvae *Placopecten magellanicus* on Georges Bank: vertical distribution in relation to water column stratification and food. Marine Ecology Progress Series. 61:1-15.

Tremblay, M.J., Loder, J.W., Werner, F.E., Naimie, C.E., Page, F.H., and Sinclair, M.M. 1994. Drift of seal scallop larvae *Placopecten magellanicus* on Georges Bank: A model study of the roles of mean advection, larval behavior and larval origin. Deep-Sea Research II. 41:7-49.

Trzcinski M.K., S.L. Armsworthy, S. Wilson, R.K. Mohn, and S.E. Campana. 2009. A framework for the assessment of the Scotian shelf and southern Grand Banks Atlantic Halibut Stock. Working Paper 2009/01.

Turner, N.B., Tyler, A.O., Falconer, R.A., and Millward, G.E. 1995. Modeling contaminant transport in estuaries. Water Research. 30:63-74.

Turnpenny, A.W.H. and Nedwell, J.R. 1994. Consultancy Report. The effects on marine fish, diving mammals and birds of underwater sound generated by seismic surveys. Fawley Aquatic Research Laboratories, Ltd. 40pp.

Uchupi, E. and Bolmer, S.T. 2008. Geologic evolution of the Gulf of Maine region. Earth Science Reviews. 91:27-76.

Ullman, D.S., Dale, A.C., Hebert, D., and Barth, J.A. 2003. The front on the northern edge of Georges Bank in Spring, Part II: Cross-frontal fluxes and mixing. Journal of Geophysical Research. 108:8010. 14pp.

USBEM (United States Bureau of Energy Management). 2010. Offshore Statistics by Water Depth. Website <www.gomr.boemre.gov/homepg /fastfacts/WaterDepth/WaterDepth.html> (cited 21 October 2010).

USMMS (United States Mineral Management Service. 2000. Georges Bank petroleum exploration. Atlantic Outer Continental Shelf, Georges Bank Compilation of Continental Offshore Stratigraphic Test (COST) and Industry Exploration Drilling, 1976-1982, OCS Report MMS 2000-040. Edson, G.M., Olson, D.L., and Petty, A.J. (eds.). Gulf of Mexico OCS Region, U.S.

Uzmann, J.R., Cooper, R.A., Theroux, R.B., and Wigley, R.L. 1977a. Synoptic comparison of three sampling techniques for estimating abundance and distribution of selected megafauna: submersible vs camera sled vs otter trawl. Marine Fisheries Review. 39:11-19.

Uzmann, J.R., Cooper, R.A., and Pecci, K.J. 1977b. Migration and dispersion of tagged American lobsters, *Homarus americanus*, on the southern New England continental shelf. Report NMFS-SSRF--705, Northeast Fish.Cent., NMFS, WoodsHole, MA, USA.

Vagle, S., Chandler, P., and Erickson, N. 2005. Marine mammal vocalization data from the Gully region off Nova Scotia. IN Acoustic Monitoring and Marine Mammal Surveys in the Gully and Outer Scotian Shelf Before and During Active Seismic Programs. Environmental Studies Research Funds Report No.151. Lee, K., Bain, H., and Hurley, G.V. (eds). Environmental Studies Research Funds, Calgary, Alberta. 139-146

Valentine, P.C. and Lough, R.G. 1991. The sea floor environment and the fishery of eastern Georges Bank – the influence of geological and oceanographic environmental factors on the abundance and distribution of fisheries resources of the northeast United States continental shelf. U.S. Geological Survey, Open- File Report 91-439, Washington, D.C.

Van Eeckhaute, L.A.M., Gavaris, S., and Trippel, E.A. 1999. Movements of haddock on eastern Georges Bank determined from a population model incorporating temporal and spatial detail. Fishery Bulletin. 97:661-679.

Varlamov, S.M., Yoon, J.H., Hirose, N., Kawamura, H., and Shiohara, K. 1999. Simulation of the oil spill processes in the Sea of Japan with regional ocean circulation model. Journal of Marine Science and Technology. 4:94-107.

Veil, J.A. 2006. Comparison of two International Approaches to controlling risk from produced water discharges. Presented at the 70th PERF Meeting, March 21-22, 2006, Paris, France.

Veil, J.A., Burke, C.J., and Moses, D.O. 1995. Synthetic Drilling Fluids – A pollution prevention opportunity for the oil and gas industry, US Department of Energy. Office of Scientific and Technical Information (OSTI) Conf-95 1023-1.

Veil, J.A., Puder, M.G., Elcock, D., and Redweik, R.J.Jr. 2004. A white paper describing produced water from production of crude oil, natural gas, and coal bed methane. Report to the U.S. Dept. of Energy, National Energy Technology Laboratory. Argonne National Laboratory, Washington, D.C. 79pp.

Veil, J.A., Kimmell, T.A., and Rechner, A.C. 2005. Characteristics of produced water dicharged to the Gulf of Mexico hypoxic zone. Report to the U.S. Dept. of Energy Technology Laboratory from Argonne National Laboratory, Washington, D.C.

Veit, R. and Petersen, W. 1993. Birds of Massachusetts. Massachusetts Audubon Society, Lincoln.

Venosa, A.D. and Zhu, X. 2003. Biodegradation of crude oil contaminating marine shorelines and freshwater wetlands. Spill Science and Technology Bulletin. 8:163-178.

Venosa, A.D., Suidan, M.T., Wrenn, B.A., Strohmeier, K.L., Haines, J.R., Eberhart, B.L., King, D., and Holder, E. 1996. Bioremediation of an experimental oil spill on the shoreline of Delaware Bay. Environmental Science & Technology. 30:1764-1775.

Venosa, A.D., K. Lee, M.T. Suidan, S. Garcia-Blanco, S.E. Cobanli, M. Moteleb, J.R. Haines, Tremblay, G., and Hazelwood, M. 2002. Bioremediation and biorestoration of a crude oil-contaminated freshwater wetland on the St. Lawrence River. Bioremediation Journal. 6:261-281.

Walli, A., Teo, S.L.H., Boustany, A., Farwell, C.J., Williams, T., Dewer, H., Prince, E., and Block, B.A. 2009. Seasonal movements, aggregations and diving behavior of Atlantic bluefin tuna (*Thunnus Thynnus*) revealed with archival tags. PLoS ONE 4:e6151.1

Wang, Y., O'Brien, L., Clark, K., Gavaris, S., and Hatt, B. 2009. Assessment of Eastern Georges Bank Atlantic Cod for 2009. TRAC Reference Document - 2009/01. 46pp.

Waring, G.T., Josephson, E., Fairfield, C.P., Maze-Foley, K (eds.). 2007. U.S. Atlantic and Gulf of Mexico barine bammal stock assessments - 2006. NOAA Tech Memo NMFS-NE-201. 388pp.

Waring G.T., Josephson E., Fairfield-Walsh C.P., Maze-Foley, K. (eds.). 2009. U.S. Atlantic and Gulf of Mexico marine mammal stock assessments - 2008. NOAA Tech Memo NMFS NE 210. 440pp.

Weilgart, LS. 2007. The impacts of anthropogenic ocean noise on cetaceans and implications for management. Canadian Journal of Zoology. 85:1091-1116.

Weir, C.R. 2007. Observations of marine turtles in relation to seismic airgun sound off Angola. Marine Turtle Newsletter. 116:17–20.

Wells, P.G., Blaise, C., and Lee, K. 1998. Microscale Aquatic Toxicology: Advances Techniques and Practice. Wells, P.G., Lee, K., and Blaise, C. (eds.). CRC Press, Inc., Boca Raton, Florida. 679 pp.

Werner, F.E., Page, F.H., Lynch, D.R., Loder, J.W., Lough, R.G., Perry, R.I., Greenberg, D.A., and Sinclair, M.M. 1993. Influences of mean advection and simple behaviour on the distributions of cod and haddock early life stages on Georges Bank. Fisheries Oceanography. 2:43-64.

Weston, S.M.C. 1992. The Canadian Federal Environmental Assessment and Review Process: An Analysis of the Initial Assessment Phase (A Report Prepared for the Canadian Environmental Assessment Research Council). Minister of Supply and Services Canada, Ottawa, Canada. Catalogue NO. EN 107-3121-1 992. 15pp.

Whitehead, H., Bowen, W.D., Hooker, S.K., and Gowans, S. 1998. Marine Mammals. IN The Gully: A Scientific Review of Its Environment and Ecosystem. Harrison, W.G. and Fenton, D.G., (eds.). DFO Can. Stock Assess. Sec. Res. Doc. 98/83. 186-221.

Wiebe, P.H. and Beardsley, R.C. 1996. Physical-biological interactions on Georges Bank and its environs. Deep Sea Research II. 43:1437-1438.

Wiebe P.H., Beardsley, R.C., Mountain, D.G., and Bucklin, A. 2002. U.S. GLOBEC Northwest Atlantic/Georges Bank Program. Oceanography. 15:13-29.

Wiese, F. 2002. Seabirds and Atlantic Canada's Ship-source Oil Pollution. Toronto: World Wildlife Fund, Toronto, Ontario.

Wigley. R.L. 1961. Benthic fauna of Georges Bank. IN Transactions of the 26th North American Wildlife and Natural Resources Conference, March 6, 7, and 8, 1961. 310-317.

Wigley, S.E., Brodziak, J.K.T., and Col, L. 2003. Assessment of the Gulf of Maine and Georges Bank witch flounder stock for 2003. Northeast Fish. Sci. Cent. Ref. Doc. 03-14. 186pp.

Wilson, R.D., Monaghan, P.H., Osanik, A., Price, L.C., and Rogers, M.A. 1974. Natural marine oil seepage. Science. 184:857-865.

Wilson-Ormond E.A., Ellis, M.S., and Powel, E.N. 1994. The effect of proximity to gas producing platforms on size, stage of reproductive development and health in shrimp and crabs. IN National Fisheries Association Annual Meeting Abstracts, April 24-28, 1994, Charleston, South Carolina. 306pp.

Wise, J.P. 1958. The world's most indigenous cod. Journal du Conseil. 23:208-212.

Wishner K.F., Gifford, D.J., Sullican, B.K., Bisagni, J.J., Outram, D.M., and Van Keuren, D.E. 2003. Biological signature of Scotian Shelf Water crossovers on Georges Bank during spring 1997. Journal of Geophysical Research. 108:8014. 21pp.

Witt, M.J., Baert, B., Broderick, A.C., Formia, A., Fretey, J., Gibudi, A., Mounguengui, G.A., Moussounda, C., Ngouessono, S., Parnell, R.J., Roumet, D., Sounguet, G-Y., Verhage, B., Zogo, A., and Godley, B.J. 2009. Aerial surveying of the world's largest leatherback turtle rookery: a more effective methodology for large-scale monitoring. Biological Conservation.142:1719-1727.

Wolff, N. and Incze, L.S. 2009. Hypsometric characterization of the Gulf of Maine, Georges Bank, Scotian Shelf and neighbouring continental slope. Website <http://research.usm.maine.edu/gulfofmaine-census/about-the-gulf/physical-characteristics/bathymetry/hypsometric-characterization-of-the-gulf-of-maine-georges-bank-scotian-shelf> (cited 3 February 2010).

Woodin, B.R., Smolowitz, R.M., and Stegeman, J.J. 1997. Induction of cytochrome P450 1A in the intertidal fish *Anoplarchus purpurescens* by Prudhoe Bay crude oil and environmental induction in fish from Prince William Sound. Environmental Science and Technology. 31:1198-1205.

Worcester, T. 2006. Effects of seismic energy on fish: a literature review. DFO Can. Sci. Advis. Sec. Res. Doc.2006/092. 66pp.

Xiong, D.Q., Reed, M., and Ekrol, N. 2000. Biological exposure models for oil spill impact analysis. Journal of Environmental Sciences. 12:482-485.

Xue, H., Chai, F., and Pettigrew, N. 2000. A model study of the seasonal circulation in the Gulf of Maine. Journal of Physical Oceanography. 30:1111-1135.

Xue, H., Incze, L., Xu, D., Wolff, N., and Pettigrew, N. 2008. Connectivity of lobster populations in the coastal Gulf of Maine. Part I: Circulation and larval transport potential. Ecological Modelling. 210:193-211.

Yano, K. 1995. Reproductive biology of the Black Dogfish, *Centroscyllium fabricii*, collected from the waters off western Greenland. Journal of the Marine Biological Association of the United Kingdom. 75:285-310.

Yeats, P.A., Law, B.A., and Milligan, T.G. 2011. The distribution of dissolved and particulate metals and nutrients in the vicinity of the Hibernia offshore oil and gas platform. IN Produced Water Discharge from Offshore Oil and Gas Facilities: Environmental Risks and Advances in Mitigation Technologies. Lee, K., and Neff, J. (eds.). Springer Publishing Company, New York. 492pp.

Yeung, C.W., Lee K., and Greer, C.W. 2011. Microbial community characterization of produced water from the Hibernia Oil Production Platform. IN Produced Water Discharge from Offshore Oil and Gas Facilities: Environmental Risks and Advances in Mitigation Technologies. Lee, K., and Neff, J. (eds.). Springer Publishing Company, New York. 492pp.

Zeiber, R. 2008. Tagging 2008: A report on the Northeast regional tagging symposium. New Hampshire sea grant college program. October 17, 2008, Durham, New Hampshire. UNHMP-R-SG-09-02.

Zhang X. 1995. Ocean outfall Modeling – Interfacing Near and Far Field Models with Particle Tracking Method. Ph.D. thesis, Massachusetts Institute of Technology.

Zhao, L., Chen, Z., and Lee, K. 2008. A risk assessment model for produced water discharge from offshore petroleum platforms-development and validation, Marine Pollution Bulletin. 56:1890-1897.

Zhu, S., King, S.C., and Haasch, M.L. 2008. Biomarker induction in tropical fish species on the Northwest Shelf of Australia by produced formation water. Marine Environmental Research. 65:315-324.

Zitko, V, L.E. Burridge, M. Woodside, and H. Akagi. 1984. Low contamination of fish by hydrocarbons from the Uniacke *G-72* (Shell Oil, Vinland) wellsite blowout in February 1984. Can. Tech. Rep. Fish. Aquat. Sci. 1305. iii + 43 p.

Zobell,C.E. 1973. Microbial degradation of oil: Present status, problems and perspectives. IN The Microbial Degradation of Oil Pollutants No. LSU-5G-73-01. Ahearn D.G. and Meyers, S.P. (eds.). Centre for Wetland Resources, Louisiana State University, Baton Rouge, Louisiana. 3-16.

Zwanenburg, K.C.T., Bundy, A., Strain, P., Bowen, W.D., Breeze, H., Campana, S.E., Hannah, C., Head, E., and Gordon, D. 2006. Implications of ecosystem dynamics for the integrated management of the Eastern Scotian Shelf. Can. Tech. Rep. Fish. Aquat. Sci. 2652. xiii + 91pp.

APPENDIX: Summary of marine species that may be found in the Georges Bank moratorium area.

Species	Range in Northwest Atlantic	Habitat	Relevance of Georges Bank to Species	Season	Diet	Abundance	Status	Known vulnerabilities
Corals **(ahermatypic)**	North Atlantic	Benthic: shelf and slope	Northeast Channel Coral Conservation Area established (2002) within moratorium boundaries to protect high density of gorgonian corals. Provide complex habitat, feeding opportunities for aggregating species, hiding places, nursery and spawning sites for other species, and attachment substrate for fish egg cases and sedentary invertebrates	Year-round	Filter feeders-phytoplankton		Conservation area established 2002	Damage from bottom contacting activities. Ingestion of inorganic and organic contaminants in water and sediments
Sea scallop	Labrador to North Carolina	Benthic: coastal and shelf, sand, gravel 35-120 m	Very productive area with high growth rates. May have self-sustaining population: spawn May -June and Aug-Oct.	Year-round	Filter feeders-phytoplankton	Increasing (recruited adults)	No SARA or COSEWIC status	Ingestion of contaminants through filter feeding. Chronic contamination has sub-lethal effects on growth and reproduction; Settled animals vulnerable to growth inhibition by drilling muds
Lobster	Labrador to Maryland	Benthic: coastal and shelf	May have self sustaining population, some gene flow with Cape Cod and Southern Channel, Adults migrate onto plateau in summer to molt and mate, release eggs following summer.	Year-round	Larvae - zooplankton Adults - benthic invertebrates and fish	Increasing (recruited adults)	No SARA or COSEWIC status	Contaminants shown to have growth and developmental effects on larval pelagic phase as well as juvenile and adult lobsters. Larval pelagic phase vulnerable to water contaminants, with potential growth and developmental effects. High and low sound levels can affect feeding and serum biochemistry. Physical barriers prevent seasonal migrations.
Red crab	Nova Scotia to Florida	Benthic: shelf and slope 300-900 m	Large numbers of larvae collected over bank. These settle in deep water, migrating into shallower water as they mature. Egg bearing females found year round. Females occur more shallow than males.	Year-round	Larvae-zooplankton Adults opportunistic: benthic invertebrates, squid, demersal and pelagic fish species	Increasing	No SARA or COSEWIC status	No information

APPENDIX: Summary of marine species that may be found in the Georges Bank moratorium area.

Species	Range in Northwest Atlantic	Habitat	Relevance of Georges Bank to Species	Season	Diet	Abundance	Status	Known vulnerabilities
Jonah crab	Newfoundland to South Carolina	Benthic: shelf 50-300 m	May migrate onshore from spring to fall and offshore in winter. Spawning period in other areas late winter to early spring.	Year-round	Larvae - zooplankton Adults - opportunistic on benthic invertebrates, squid, demersal and pelagic fish species	Declining	No SARA or COSEWIC status	No information
Northern Shortfin squid	Newfoundland to Florida	Pelagic: shelf and slope. Depth varies seasonally.	May be an important feeding ground during migration to/from Gulf of Maine in spring and fall.	Spring, Summer, Fall	Ontogenetic shift from crustaceans to fish and squid	Variable	No SARA or COSEWIC status	Sensitive to noise-alter behaviour 2-5 km from seismic source
Longfin squid	Georges Bank to North Carolina	Demersal by day, pelagic at night: shelf and slope. Depth varies seasonally.	Spawning on Georges Bank occurs late spring early summer.	Spring and Summer	Ontogenetic shift from plankton to crustaceans, small fish and squid	Variable; low relative to 1999-2002	No SARA or COSEWIC status	Sensitive to noise-alter behaviour 2-5 km from seismic source

APPENDIX: Summary of marine species that may be found in the Georges Bank moratorium area.

Species	Range in Northwest Atlantic	Habitat	Relevance of Georges Bank to Species	Season	Diet	Abundance	Status	Known vulnerabilities
Herring	Labrador to North Carolina	Pelagic: shelf and slope waters spring through fall	Adult portion of population over-winters South of Cape Cod, migrates onto Bank in summer for feeding and spawning. Spawning occurs along entire northern reach. Benthic spawners, demersal eggs hatch in 10-12 days, pelagic larvae 6 months; juveniles may migrate inshore in summer.	Adults: Summer and Fall; juveniles year-round	Plankton copepods, chaetognaths, krill	Increasing	No SARA or COSEWIC status	Spawns in relatively small and select locations: may be affected by disturbance and contaminants. Can detect broad range of sounds: if noise alters migration or spawning patterns, this would affect both herring and its several predators
Mackerel	Labrador to North Carolina	Pelagic: shelf and slope spring through fall	Spring and Fall migration over Georges Bank to/from spawning area in Gulf of St Lawrence. Juveniles and adults caught in RV surveys along sides of Bank, seldom on top.	Spring and Fall	Copepods, krill, shrimp, squid, fish	Declining, fewer older fish	No SARA or COSEWIC status	Pelagic eggs susceptible to contaminants. Lack of swim bladder reduces effect of sound pressure on animals
Sand lance	Greenland to North Carolina	Demersal by day; Pelagic by night; shelf	Species complex. Non-migratory. Burrow into substrate by day, vertically migrate nightly to feed in water column. Spawn November to March; demersal eggs; pelagic larvae until 35 mm length	Year-round	Larvae - phytoplankton, diatoms; Juveniles, adults - copepods, polychaete larvae, krill, mysids, crabs	Variable recruitment and abundance	No SARA or COSEWIC status	Demersal eggs are vulnerable to bottom disturbance and contamination.

APPENDIX: Summary of marine species that may be found in the Georges Bank moratorium area.

Species	Range in Northwest Atlantic	Habitat	Relevance of Georges Bank to Species	Season	Diet	Abundance	Status	Known vulnerabilities
Atlantic cod	Greenland to North Carolina	Demersal; coastal and shelf	Resident population with exchange with Browns Bank and Great South Channel. Northeast peak is an important nursery area for juveniles and is a habitat that provides an important food source.	Year-round	Larvae - phytoplankton, zooplankton; Juveniles, adults- crabs, molluscs, and fish (herring, sand lance)	Declining since 1990s, possible increase since 2005	No SARA status COSEWIC (2010) Endangered	Swim bladder is vulnerable to changes in pressure, sounds produced by swim bladder may be part of courtship rituals. Life history of larval pelagic phase followed by demersal juveniles and adults with benthic feeding enhances susceptibility to contaminants in both water column and benthos and activities that disturb the bottom.
Haddock	Greenland to North Carolina	Demersal:45-240 m; shelf	Resident population, seasonal migration to deeper water in summer. A major spawning concentration resides on the northern edge of the bank and Northeast Peak	Year-round	Larvae - phytoplankton, zooplankton; Juveniles and adults-benthic invertebrates crustaceans, molluscs, fish and echinoderms	Increasing	No SARA or COSEWIC status	Swim bladder is vulnerable to changes in pressure, sounds produced by swim bladder may be part of courtship rituals. Life history of larval pelagic phase followed by demersal juveniles and adults with benthic feeding enhances susceptibility to contaminants in both water column and benthos and activities that disturb the bottom
Pollock	Labrador to North Carolina	Demersal; coastal and shelf to 380 m	Western component stock extends from Gulf of Maine to 4X portion of Scotian Shelf. Spawning on northeastern Georges Bank November-December; eggs and larvae present November to February.	Year-round	Juvenile-crustaceans and small fish Adult-euphausiids, squid and fish	Increasing since 2000	No SARA or COSEWIC status	Swim bladder is vulnerable to changes in pressure, sounds produced by swim bladder. May be sensitive to excess noise.

APPENDIX: Summary of marine species that may be found in the Georges Bank moratorium area.

Species	Range in Northwest Atlantic	Habitat	Relevance of Georges Bank to Species	Season	Diet	Abundance	Status	Known vulnerabilities
Monkfish	Newfoundland to North Carolina	Demersal: shelf; 70-190 m (>800 m)	Georges Bank population has northern and southern components, northern maybe continuous with Scotian Shelf. Seasonal onshore-offshore migrations. Peak spawning May-June.	Year-round	Larvae-zooplankton; Juveniles-fish, crustaceans; Adults- fish, crustaceans and squid	Declining	No SARA or COSEWIC status	No information
Cusk	North Atlantic	Demersal: shelf and slope to 600 m (1185 m max)	Occur mainly in Northeast Channel, on Northeast Peak, in Fundian Channel, also on Georges Bank. Spawning on Scotian Shelf occurs May-August.	Year-round	Invertebrates (crab and shrimp) and fish.	Declining	No SARA status COSEWIC (2003, 2006) Threatened	Vocalizations associated with aggressive behaviour, thus may be vulnerable to anthropogenic noise.
Redfish	Baffin Island to Gulf of Maine	Semi-pelagic: 100-700 m	Occur in the deep basins along the continental slope.	Year-round	Larvae -krill, copepods, fish and invertebrate eggs Adults: krill, mysids, fish	Increasing since 2001	No SARA status COSEWIC (2010) Threatened	Life history characteristics of late maturity and slow growth rates make this species susceptible to bottom activities causing disturbances.
Atlantic wolffish	Davis Strait to Massachusetts	Demersal: shelf; 22-275 m (350 m max)	Distributed throughout the Bank with concentrations found along the Northeast Peak and along the Great South Channel. Mature animals move inshore in summer. Spawn in September.	Year-round	Bivalves, echinoderms, gastropods and decapods	Declining	SARA Special Concern COSEWIC (2000) Special Concern	Nest spawning make the eggs susceptible to bottom activities causing disturbances or contamination.

APPENDIX: Summary of marine species that may be found in the Georges Bank moratorium area.

Species	Range in Northwest Atlantic	Habitat	Relevance of Georges Bank to Species	Season	Diet	Abundance	Status	Known vulnerabilities
Atlantic halibut	Labrador to Virginia	Demersal: shelf and slope 200-500 m	Resident; seasonal migration to deeper waters in winter; extensive migrations throughout range.	Year-round	Ontogenetic shift from cephalopods, crustaceans and benthic invertebrates to fish	Declining	No SARA or COSEWIC status	No information
Yellowtail flounder	Labrador to North Carolina	Demersal: shelf; 37-73 m	Resident transboundary stock; benthic spawning late March-August; juveniles and adults concentrate on southern edge and northern peak in spring, throughout bank other seasons.	Year-round	Benthic invertebrates (amphipods, mysids, worms, sand dollars) and small fish	Increasing	No SARA or COSEWIC status	Life history characteristics of demersal dwelling, feeding, and egg laying make this species susceptible to bottom activities causing disturbances or contamination.
Witch flounder	Labrador to North Carolina	Demersal: shelf and slope 50-300 m	Resident population, peak spawning May to August	Year-round	Benthic polychaetes, crustaceans, bivalves, echinoderms	Increasing	No SARA or COSEWIC status	Life history characteristics of demersal dwelling, feeding, and egg laying make this species susceptible to bottom activities causing disturbances or contamination.
Winter skate	Newfoundland to North Carolina	Demersal: shelf; <1-371 m	Seasonal migration into shallow waters in summer. Georges Bank may be primary spawning ground for US population; Spawning occurs on Scotian shelf September to November	Year-round	Juveniles - sand shrimp, crabs, isopods, amphipods; Adults - invertebrates and fish	Variable; no trend	No SARA status COSEWIC (2005) Special Concern	Larval stage susceptible to bottom disturbance due to long incubation
Little skate	Scotian Shelf to Cape Hatteras	Demersal: shelf; <111 m (384 m max)	Widespread and abundant on Georges Bank, egg laying throughout year with peak in fall and winter.	Year-round	Decapod crustaceans, amphipods, polychaetes, fish	Variable; no trend	No SARA or COSEWIC status	Life history characteristics of demersal dwelling, feeding, and egg laying make this species susceptible to bottom activities causing disturbances or contamination

APPENDIX: Summary of marine species that may be found in the Georges Bank moratorium area.

Species	Range in Northwest Atlantic	Habitat	Relevance of Georges Bank to Species	Season	Diet	Abundance	Status	Known vulnerabilities
Thorny skate	North Atlantic	Demersal: shelf <60 m	Uncommon on Georges Bank except in deeper portions of Northeast Peak, may be part of Gulf of Maine or Fundian Channel population.	Year-round, uncommon	Decapod crustaceans, amphipods, polychaetes, fish	Declining	No SARA or COSEWIC status	Life history characteristics of demersal dwelling, feeding, and egg laying make this species susceptible to bottom activities causing disturbances or contamination
Smooth skate	Newfoundland to South Carolina	Demersal: shelf, >90 m	Uncommon on Georges Bank except in deeper portions of Northeast Peak, little information about life history.	Year-round	Amphipods, decapods, krill, mysids	Low abundance, no trend	No SARA or COSEWIC status	Life history characteristics of demersal dwelling, feeding, and egg laying make this species susceptible to bottom activities causing disturbances or contamination
Barndoor skate	Labrador to North Carolina	Demersal: shelf, >1600 m	Population on Georges Bank restricted to southern portion of Georges Bank, may be continuous with Scotian Shelf population.	Year-round	Ontogenetic shift from shrimp, crabs to fish (sculpins, red hake, herring, ocean pout)	Variable, no trend	No SARA or COSEWIC status IUCN (2003) Endangered	Life history characteristics of demersal dwelling, feeding, and egg laying make this species susceptible to bottom activities causing disturbances or contamination
Spiny dogfish	Newfoundland to North Carolina	Benthopelagic: shelf	Migratory and resident populations in Northwest Atlantic; may be important mating area	Year-round	Invertebrates and fish	Decline since 1990s	No SARA status COSEWIC (2010) Special Concern	Life history characteristics of a long gestation period, low fecundity and growth rate make this species susceptible to increased mortality from sources including human activities. Attracted by high-level, low-frequency pulses, which may affect shark interactions and ability to detect prey
Black dogfish	Greenland to North Carolina	Bathydemersal: slope	May occur at edges of Bank	Not known	Invertebrates (crustaceans, squid, jellyfish, cephalopods) and fish	Insufficient information	No SARA or COSEWIC status	Attracted by high-level, low-frequency pulses: these may affect shark interactions and ability to detect prey
Swordfish	All North Atlantic (Newfoundland to Argentia)	Pelagic: shelf and slope; diving to depths of 800 m	Migrates onto Georges Bank, Northeast Peak is an important foraging area from June to October	Summer, Fall	Invertebrates (short-finned squid) and fish (barracudina, lanternfish, silver hake)	Increasing	No SARA or COSEWIC status	Any activities disrupting behaviour of schooling prey species will cause swordfish to move to alternative foraging habitats

APPENDIX: Summary of marine species that may be found in the Georges Bank moratorium area.

Species	Range in Northwest Atlantic	Habitat	Relevance of Georges Bank to Species	Season	Diet	Abundance	Status	Known vulnerabilities
Bluefin tuna	All North Atlantic (Newfoundland to Gulf of Mexico)	Pelagic: oceanic, < 200 m	Migrate onto Georges Bank June and July and remain until November. Important foraging habitat.	Summer, Fall	Juveniles - fish, squid, crustaceans; Adults – fish (herring, anchovy, sand lance, sardine, sprat, mackerel)	Declining	No SARA status Under review by COSEWIC and CITES	Any activities disrupting behaviour of schooling prey species will cause bluefin tuna to move to alternative foraging habitats
Yellowfin tuna	North Atlantic (Nova Scotia to Argentina)	Pelagic: oceanic	Migrate to near northern edge of Georges Bank July to November. Important foraging habitat.	Summer, Fall	Fish and squid	Abundant	No SARA or COSEWIC status	Any activities disrupting behaviour of schooling prey species will cause yellowfin tuna to move to alternative foraging habitats
Bigeye tuna	North Atlantic (Nova Scotia to Argentina)	Pelagic: oceanic	Migrate to near northern edge of Georges Bank July to November. Important foraging habitat.	Summer, Fall	Fish, squid, krill	Declining	No SARA or COSEWIC status	Any activities disrupting behaviour of schooling prey species will cause bigeye tuna to move to alternative foraging habitats
Albacore tuna	North Atlantic (Nova Scotia to Argentina)	Pelagic: oceanic	Migrate to near northern edge of Georges Bank July to November. Important foraging habitat.	Summer	Fish (sardine, mackerel, anchovy), squid, and crustaceans	Declining	No SARA or COSEWIC status	Any activities disrupting behaviour of schooling prey species will cause albacore tuna to move to alternative foraging habitat
Porbeagle shark	North Atlantic (Newfoundland to New Jersey)	Pelagic: shelf	Adults migrate over Georges Bank in summer; Important mating area with females congregating in preparation for mating in June.	Summer, Fall	Pelagic and demersal fish species, squid and shellfish	Decline: 25% of virgin population	No SARA status COSEWIC (2004) Endangered	Attracted by high-level, low-frequency pulses: affect shark interactions, detection of prey
Thresher shark	Newfoundland to Cuba	Pelagic: shelf	Juveniles, adults migrate onto Georges Bank in summer.	Summer	Pelagic fish species, crustaceans, squid, octopi	Decline: 75% since 1986	No SARA or COSEWIC status	Attracted by high-level, low-frequency pulses: affect shark interactions, detection of prey.

APPENDIX: Summary of marine species that may be found in the Georges Bank moratorium area.

Species	Range in Northwest Atlantic	Habitat	Relevance of Georges Bank to Species	Season	Diet	Abundance	Status	Known vulnerabilities
Basking shark	All North Atlantic	Pelagic: shelf	Migrate onto bank for feeding during summer and fall, may form mating congregations in summer.	Spring, Summer, Fall	Plankton	Decline in Canadian data, no trend in US data	No SARA status COSEWIC (2009) Special Concern Listed by CITES, IUCN	Low resilience to perturbation (collisions, bycatch); attracted by high-level, low-frequency pulses: affect shark interactions, detection of prey.
Short-fin mako shark	All North Atlantic	Pelagic: shelf	Migrate into area during summer and fall.	Summer, Fall	Fish, sharks, turtles, marine mammals and squid	Decline since 1970	No SARA status COSEWIC (2006) Threatened	Low resilience to perturbation and exploitation; attracted by high-level, low-frequency pulses: affect shark interactions, detection of prey
Blue shark	All North Atlantic (Newfoundland to Argentina)	Pelagic: shelf	Migrate into area during May to October	Spring, Summer, Fall	Pelagic and demersal fish species, invertebrates	Variable estimates: no change to decline since 1980s	No SARA status COSEWIC (2006) Special concern	Attracted by high-level, low-frequency pulses: affect shark interactions, detection of prey
Hammerhead shark	Nova Scotia to Florida	Pelagic: shelf	Migrates into Canadian waters in summer, uncommon in Georges Bank.	Summer	Pelagic fish species (herring, menhaden), rays, skates, sharks, squids, crabs	Decline: 89% since 1986	No SARA or COSEWIC status	Attracted by high-level, low-frequency pulses: affect shark interactions, detection of prey
White shark	Global but uncommon in North Atlantic	Pelagic: shelf	Infrequent occurrence in Atlantic Canada: migration into region in summer	Summer	Fish species and marine mammals	Decline: 80% since 1990	No SARA status COSEWIC (2006) endangered	Attracted by high-level, low-frequency pulses: affect shark interactions, detection of prey

APPENDIX: Summary of marine species that may be found in the Georges Bank moratorium area.

Species	Range in Northwest Atlantic	Habitat	Relevance of Georges Bank to Species	Season	Diet	Abundance	Status	Known vulnerabilities
North Atlantic right whale	Gulf of St Lawrence to Florida	Pelagic, shelf	Seasonal migrations over Bank in Spring and Fall, foraging area during Summer	Spring, Summer, Fall	Zooplankton (primarily *Calanus*)	Increase: 30% during last decade	SARA endangered COSEWIC (1980, 2003) endangered	Entanglement in fishing gear, collisions with vessels, noise, vessel disturbance, contaminants, and environmental or habitat change
Fin whale	All Northwest Atlantic	Pelagic: shelf	Seen on Bank year-round but abundance fluctuates due to seasonal migrations from tropical wintering areas to temperate summer feeding grounds	Year-round	Pelagic fish species (herring, capelin) and squid, krill, mysids	Insufficient information	SARA Special Concern COSEWIC (1987, 2005) Special concern	Entanglement in fishing gear, collisions with vessels, noise, vessel disturbance, contaminants, and environmental or habitat change
Sei whale	Labrador to Georges Bank	Pelagic: shelf edge, <2000 m	Occur year-round on Bank, higher concentration in Spring and Summer	Year-round	Zooplankton (copepods)	Insufficient information	No SARA status COSEWIC (2003) Data Deficient	Entanglement in fishing gear, collisions with vessels, noise, vessel disturbance, contaminants, and environmental or habitat change
Minke whale	Davis Strait to Gulf of Mexico	Pelagic: shelf	Occur on Bank in Spring and Summer	Spring, Summer	Crustaceans, plankton and small pelagic fishes	Insufficient information	No SARA status COSEWIC (2006) Not at Risk	Entanglement in fishing gear, collisions with vessels, noise, vessel disturbance, contaminants, and environmental or habitat change
Humpback whale	Greenland to West Indies	Pelagic: coastal	Seasonal migrations over Bank in Spring and Fall, foraging area during Summer	Spring, Summer, Fall	Crustaceans, plankton and small fish	Increasing	SARA Special Concern COSEWIC (2003) Not at Risk	Entanglement in fishing gear, collisions with vessels, noise, vessel disturbance, contaminants, and environmental or habitat change

APPENDIX: Summary of marine species that may be found in the Georges Bank moratorium area.

Species	Range in Northwest Atlantic	Habitat	Relevance of Georges Bank to Species	Season	Diet	Abundance	Status	Known vulnerabilities
Sperm whale	Nova Scotia to Cape Hatteras	Pelagic: shelf and slope <1000 m	Males occur year-round on Bank, population distributed over southern portion of Georges Bank in Spring, northern and eastern portions in summer	Year-round	Mesopelagic and benthic squid and fish species	Insufficient information	No SARA status COSEWIC (1996) Not at Risk	Entanglement in fishing gear, collisions with vessels, noise, vessel disturbance, contaminants, and environmental or habitat change
Pilot whale	Western Atlantic	Pelagic: shelf and slope	All year, higher prevalence in spring-summer	Year-round	Squid species	Insufficient information	No SARA status COSEWIC (1994) Not at Risk	Entanglement in fishing gear, collisions with vessels, noise, vessel disturbance, contaminants, and environmental or habitat change
Bottlenose dolphin	Scotian Shelf to tropics	Pelagic: coastal and shelf	All year, higher prevalence in spring-summer	Year-round	Fish, squid and invertebrates	Insufficient information	No SARA status COSEWIC (1993) Not at Risk	Entanglement in fishing gear, collisions with vessels, noise, vessel disturbance, contaminants, and environmental or habitat change
White-sided dolphin	Greenland to North Carolina	Pelagic: shelf	Present on Bank all year, lower abundance in winter	Year-round	Pelagic fish species (herring, sandlance, silver hake) and squid	Insufficient information	No SARA status COSEWIC (1991) Not at Risk	Entanglement in fishing gear, collisions with vessels, noise, vessel disturbance, contaminants, and environmental or habitat change
Common dolphin	Newfoundland to Cape Hatteras	Pelagic: shelf and slope	Range from Cape Hatteras to Georges Bank in January-May, move onto Bank and Scotian Shelf in summer, form large aggregations on Bank in fall and winter	Year-round	Pelagic fish species and cephalopods	Insufficient information	No SARA status COSEWIC (1991) Not at Risk	Entanglement in fishing gear, collisions with vessels, noise, vessel disturbance, contaminants, and environmental or habitat change
Striped dolphin	Georges Bank to Cape Hatteras	Pelagic: shelf and slope	Most prevalent in summer and fall	Summer, fall	Pelagic and demersal benthic fish species and cephalopods	Insufficient information	No SARA status COSEWIC (1993) Not at Risk	Entanglement in fishing gear, collisions with vessels, noise, vessel disturbance, contaminants, and environmental or habitat change

APPENDIX: Summary of marine species that may be found in the Georges Bank moratorium area.

Species	Range in Northwest Atlantic	Habitat	Relevance of Georges Bank to Species	Season	Diet	Abundance	Status	Known vulnerabilities
Harbour porpoise	Labrador to Bay of Fundy	Pelagic: coastal and shelf	Migrates over Georges Bank in spring and fall migrations to/from coastal feeding grounds	Spring: migration	Pelagic fishes (herring, sandlance, capelin) and cod	Insufficient information	SARA Threatened COSEWIC (2003) Special Concern	Entanglements, habitat degradation, acoustic harassment devices, environmental contaminants
Blue whale	All North Atlantic (Davis Strait to Nova Scotia)	Pelagic: coastal and shelf	Uncommon occurrence on Georges Bank	Spring, Summer, Fall	Krill	Insufficient information	SARA Endangered COSEWIC (2002) Endangered	Entanglement in fishing gear, collisions with vessels, noise, vessel disturbance, contaminants, and environmental or habitat change
Sowerby's Beaked whale	All North Atlantic (Davis Strait to Cape Cod)	Pelagic: shelf and slope	Uncommon occurrence, no known seasonal migrations	Not known	Pelagic and mesopleagic fish and squid species	Insufficient information	SARA Special concern COSEWIC 2006 Special concern	Entanglement in fishing gear, collisions with vessels, noise, vessel disturbance, contaminants, and environmental or habitat change
Grey seal	All North Atlantic (Labrador to Gulf of Maine)	Pelagic: coastal and shelf 0-200 m	Sable Island population travels widely and forages on Georges Bank	Year-round	Fish, cephalopods, crustaceans and occasionally seabirds	Increasing	NO SARA status COSWEIC 1999 Not at risk	Susceptible to boat strikes, oil spill exposure, chemical contaminants and marine debris ingestion
Harbour seal	All North Atlantic	Pelagic: coastal and shelf	Occur seasonally on Georges Bank	Year-round	Fish, cephalopods and crustaceans	Increasing	No SARA status COSEWIC 2007 Not at Risk	Susceptible to boat strikes, oil spill exposure, chemical contaminants and marine debris ingestion
Leatherback turtle	Labrador to South America	Pelagic: coastal and shelf	Georges Bank area used for foraging April to December	Spring, Summer, Fall	Gelatinous zooplankton	Insufficient information	SARA Endangered COSEWIC 1981, 2001 Endangered	Entanglement in lines, vessel strikes, plastics ingestion, inferred potential disturbance from underwater sounds based on response of other turtle species to seismic surveys

APPENDIX: Summary of marine species that may be found in the Georges Bank moratorium area.

Species	Range in Northwest Atlantic	Habitat	Relevance of Georges Bank to Species	Season	Diet	Abundance	Status	Known vulnerabilities
Loggerhead turtle	Newfoundland to Argentina	Pelagic: coastal and shelf	Georges Bank area used for foraging July to October	Summer, Fall	Fish species and benthic invertebrates	Decline	No SARA status COSEWIC (2010) endangered	Entanglement in lines, vessel strikes, plastics ingestion, inferred potential disturbance from underwater sounds based on response of other turtle species to seismic surveys
Greater Shearwater	All South and North America	Pelagic	Migrate from south American breeding grounds and appear on Georges Bank area in May and remain until November.	Summer, Fall	Fish, squid, crustaceans	Abundant	No SARA or COSEWIC status IUCN: Least Concern	Vulnerable to effects of oil pollution in pelagic foraging areas; attracted to lights of offshore vessels and platforms
Red phalarope	North and South Atlantic	Pelagic	Arrive on Bank in May and feed for one month; southward migration across Bank in October	Spring, Fall	Plankton (copepods, krill, larval fish), insects	Declining	No SARA or COSEWIC status IUCN: Least Concern	Vulnerable to effects of oil pollution in pelagic foraging areas
Wilson's storm-petrels	All South and North America	Pelagic	Migrate from South American breeding grounds and appear on Georges Bank area in May, remain until October	Spring Summer, Fall	Amphipods, krill, squid, fish	Abundant	No SARA or COSEWIC status IUCN: Least Concern	Vulnerable to effects of oil pollution in pelagic foraging areas; attracted to lights of offshore vessels and platforms
Thick-billed Murre	Circumpolar Artic (Greenland to Georges Bank)	Pelagic	Migrate southwards from Arctic breeding grounds and appear on Georges Bank December through May	Winter, Spring	Fish, crustaceans, squid and annelids	Stable	No SARA or COSEWIC status IUCN: Least Concern	Vulnerable to effects of oil pollution in pelagic foraging areas; high mortality shown near Newfoundland shown to be due to chronic oil pollution
Northern Fulmar	Arctic to Georges Bank	Pelagic	Migrate southwards from Arctic breeding grounds, common on Georges Bank January through March but sighted year round.	Year-round (except August)	Fish, cephalopods and zooplankton	Stable	No SARA or COSEWIC status IUCN: Least Concern	Vulnerable to effects of oil pollution in pelagic foraging areas

APPENDIX: Summary of marine species that may be found in the Georges Bank moratorium area.

Species	Range in Northwest Atlantic	Habitat	Relevance of Georges Bank to Species	Season	Diet	Abundance	Status	Known vulnerabilities
Black legged Kittwake	Arctic Ocean to Georges Bank	Pelagic	Migrate south from breeding grounds in Arctic, Iceland and eastern Atlantic, and appear on Georges Bank October through April	Fall, Winter, Spring	Fish and invertebrates	Expanding except for Newfoundland colonies	No SARA or COSEWIC status IUCN: Least Concern	Vulnerable to effects of oil pollution in pelagic foraging areas: oil spills in Alaska killed thousands
Northern gannet	Newfoundland to Florida	Pelagic	Southward migration from breeding grounds to wintering locations: abundant on Georges Bank from October to December and March through May	Fall, Spring	Fish	Increasing	No SARA or COSEWIC status IUCN: Least Concern	Not as directly affected by oil spills as other seabirds
Herring gull	Baffin Island to Cape Hatteras	Pelagic	Occur on Georges Bank year-round	Year-round	Fish, invertebrates, insects, other seabirds and eggs	Decline	No SARA or COSEWIC status IUCN: Least Concern	Vulnerable to effects of oil pollution in pelagic foraging areas
Great Black-backed gull	Florida to Hudson Strait	Pelagic	Immature birds common on Georges Bank in spring, also wintering area for northern breeding colonies	Spring, Winter	Fish, invertebrates, mammals, insects, other seabirds and eggs	Expanding except for Nova Scotia colonies	No SARA or COSEWIC status IUCN: Least Concern	Vulnerable to effects of oil pollution in pelagic foraging areas